Crime Scene Investigations through Augmented Reality

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by

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List of publications:

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Abstract

Traditional forensic investigation training faces challenges such as time-intensive processes, geographical limitations, accessibility barriers, and contamination risks to crime scenes. This study introduces a two-fold approach to modernize training while addressing these challenges. An extensive literature review on 3D scanning for crime scene reconstruction and an examination of Extended Reality (XR) technologies, including Augmented Reality (AR), Virtual Reality (VR), and Mixed Reality (MR). To understand current solutions, a hybrid theoretical framework integrates Task-technology Fit (TTF), Technology Acceptance Model (TAM), and AR headset features like immersion, interactivity, and mobility. This framework is rooted in theories from human-computer interaction, cognitive psychology, and education. The primary objective is to investigate junior investigators' behavioral intentions regarding AR headset adoption. Empirical validation is achieved through a questionnaire administered to 160 police academy students, analyzed with Partial Least Squares-Structural Equation Modeling (PLS-SEM). Beyond theory, this research conducts crime scene reconstructions using 3D scanning technology. An AR-based training system is designed, developed, and deployed, tailored for crime scene investigation training, showcasing the viability and efficiency of AR technology in this realm. System evaluation comprises quantitative feedback from 160 students and qualitative interviews with 11 experts. The findings reveal the diverse impacts of TTF and Individual Technology Fit on the perceived utility and ease of use of AR applications in investigative training. The results consistently reflect positive tendencies toward usability, user interaction, and overall satisfaction with the AR-based system, positioning it as a promising tool for future crime scene education and investigative practices. By bridging theoretical concepts with practical implementations, this work showcases the viability and effectiveness of HoloLens 2 in this domain. While presenting promising advancements, this research also underscores the importance of acknowledging the current limitations of AR technology and suggests valuable avenues for future exploration and refinement.

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Abbreviations

Extended Reality (XR)

Augmented Reality (AR)

Virtual Reality (VR)

Mixed Reality (MR)

Virtual environment (VE)

Task-technology Fit (TTF)

Technology Acceptance Model (TAM)

Extended TAM (e-TAM)

Partial Least Squares-Structural Equation Modeling (PLS-SEM).

Head-Mounted Display (HMD)

perceived usefulness (PU)

Perceived Ease of Use (PEOU)

Behavioural intention (BI)

Perceived interactivity (PI)

Immersion (IM)

Mobility (MOB)

Individual Technology Fit (ITF)

Mixed reality tools kit (MRTK)

CHAPTER 1
INTRODUCTION

1.1 Introduction

This thesis aims to explore a cutting-edge Augmented Reality Learning Environment that leverages HoloLens technology to aid in crime scene investigation (CSI). Conventional forensic investigation commonly demands a substantial amount of time at the crime scene. However, inadequate time or resources, particularly limitations of time and geographical variations among colleagues are often the case (Robey et al. 2000). Efficiently utilising investigative resources necessitates the adoption of contemporary techniques for storing, visualising, and manipulating evidence. This becomes particularly crucial as forensic investigation units are becoming increasingly technology-oriented, enabling small teams to swiftly obtain and record diverse data types. Considering this need to analyse and classify a range of data, virtual environment (VE) technology presents a valuable interface (Robey et al. 2000).

Currently, law enforcement has significantly advanced its crime-solving capabilities by embracing forensic techniques and processes. Forensic scientists contribute largely not only to criminal investigation and prosecution but also to civil litigation, disasters, and global crimes (Inman and Rudin, 2001). The success of CSI is based on a system of teamwork, investigative tools like GPS positioning, video imaging, mobile phones and data mining (Lee and Pagliaro, 2013). Crime scene investigations have successfully utilised tri-dimensional (3D) representations of objects (Carew and Errickson, 2019). It is also based on the capabilities to appropriately process a crime scene through the recognition, collection, and preservation of all significant physical evidence, defined as any evidence that can give useful information for a crime investigation (Gaensslen *et al.,* 2008; Lee and Pagliaro, 2013). Failure to recognize and appropriately handle physical evidence can result in the permanent loss of its forensic value. Despite the availability of current forensic technologies, the efficient use of physical evidence in solving a crime is only limited by the knowledge and integrity of the forensic personnel and the unbiased legal system supporting those functions. The successful outcome of the case relies on the physical evidence collected from the crime scene. However, certain cases may remain unsolved due to the absence of such crucial evidence. Conversely, some innocent individuals are made to answer for a crime that they did not commit because of witness misidentification or misused forensic evidence (Gianelli, 2007; Lee and Pagliaro, 2013).

1.1.1 Augmented Reality

Extended Reality (XR) is an umbrella term that encompasses various forms of computer-altered reality, including Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR). Extended Reality merges the physical and digital worlds by leveraging computer technology, often achieved through sensory hardware and software. While Virtual Reality offers a fully immersive digital experience, Augmented Reality superimposes digital objects into the real world. Mixed Reality is a blend of both, allowing for real-time interaction with both digital and physical objects (Milgram and Kishino, 1994).

Recent studies on the use of AR for collaboration among crime scene investigators suggest that AR fosters consensus-building within investigative teams (e.g. Lukosch *et al.*, 2015; Poelman *et al.*, 2012). AR is a technology that adds holograms to the user's view. VR fully immerses the user by completely replacing the visual environment, whereas AR combines the real environment with digital elements to enhance the user's perception of reality (Aukstakalnis, 2016). AR and MR are interchangeable terms in most academic and industrial resources and publications. Both of these terms superimpose the virtual elements on top of the real environment, however, the MR is quite more immersive in terms of the surrounding virtual objects and it has more human interaction with these virtual objects (Speicher et al., 2019).

In 1968, the first AR Head-Mounted Display (HMD) was introduced at Harvard University. The commercial use of AR began in 2008 when a German company created a 3D model of the BMW Mini for a marketing campaign. This model showcased the BMW Mini on the screen, allowing users to interact with and control it by manipulating the physical advertisement.

Subsequently, other brands followed suit and embraced a similar concept. It is worth noting that AR had already found applications in museums and tourism-related projects as early as the 2000s, with its initial introduction in university labs. As technology progressed, AR became more readily accessible and widespread. For instance, in 2013, AR was incorporated into automobile companies' service manuals, like Volkswagen's. Moreover, in 2017, Lenovo introduced the first entertainment AR headset for Star Wars, showcasing the continued expansion of AR into various domains. (Heinonen, 2018).

Datcu et al. (2014) present a system that supports situational awareness for individual teams in the security field. In this context, AR is utilised to create virtual co-location and enhance a remote colleague's telepresence, particularly in the context of forensic investigation, among other applications. Similarly, another AR system facilitating the collaboration of remote experts and local investigators in securing evidence for forensic investigations was described by Poelman *et al.* (2012). These systems offered valuable insights, highlighting key lessons, including the ability of AR technology to replicate certain spatial cues found in face-to-face collaboration. AR also excels in increasing social presence compared to other technologies, and it enables remote collaboration with a seamless, natural interaction in a real environment. (Billinghurst and Thomas, 2011).

AR continues to be a relatively young technology and is still in its early stages of development, despite the involvement of numerous major technology and software companies in its production and advancement. For example, Apple recently launched ARKit and will be developing AR glasses called Vision Pro. Facebook created AR image filters and introduced an AR development tool called AR Studio. Google introduced Tango, a platform that offers AR capabilities for mobile devices and later launched the ARCore SDK, which replaced Tango. Microsoft launched an AR headset called HoloLens (Heinonen, 2018), which this study is going to employ to investigate crime scenes. In general, AR devices are categorized into two main classifications: HMD headsets, and mobile phones. Most HMDs are characterised by transparent lenses, into which holograms are projected. An AR device may include a video see-through device in which a camera and a screen are used to show the user's content. Many devices are equipped with multiple sensors to interpret their surroundings accurately, enabling seamless interaction between holograms and the real world. (Limer, 2015).

1.1.2 Virtual Reality

Virtual Reality (VR) on the other hand, is AR's sister technology. While AR enhances one's current experience by adding digital data to the real world, VR mesmerizingly transports users to a computer-generated, entirely different environment, creating a sense of immersion and realism. VR is designed to provide a completely immersive experience that makes a person no longer in the present world; hence, the essence of presence and immersion is crucial for VR's success. In contrast, AR is not focused on creating an entirely new world in its pursuit to add computer-generated graphics to the user's current world space. The immersive characteristic of VR makes its applications essentially limited. Whenever a user decides to put on a VR headset, they are moving from where they are located to a different space/place. In contrast, AR brings virtual objects to the user, which are anchored in their physical positions while augmenting the reality around them. (Linowes and Babilinski, 2017). Moreover, the solutions employed for VR have the potential to fulfil the requirements of AR systems, as long as the user remains within the scope covered by the sensors This denotes that AR systems are not very useful if the user wants to move beyond immersive spaces (Kuntz *et al.*, 2018).

VR experiences take place with VR headsets visually blocking the real environment, which is intentional. In creating the VR experience, the application developer enables the user to see everything according to what is designed. This requirement has huge technology design and development implications. However, VR has a basic problem of motion-to-photon latency, in which once the user moves their head, the VR image needs to update rapidly, or they will risk encountering motion sickness. Latency is not much of a problem in AR since most of the visual space is real. In general, fewer graphics are rendered and not much physics is calculated in each AR frame (Linowes and Babilinski, 2017). It is essential to note that AR technology can be applied in CSI for various purposes including analysing data, evaluating witness statements, evaluating hypotheses, security planning, and courtroom-related usage, among others (Robey *et al.* 2000).

1.2 Crime Investigation

The subsequent subsections provide an overview of the nature of crime scenes and the methodologies employed in conducting investigations at these sites. Providing background information is of utmost importance to construct scenarios for evaluation purposes. The primary reference utilised in this section is sourced from the Swedish National Forensic Centre. Utilise (Valjarevic et al. 2015).

1.2.1. Crime Scene

To expound upon the collection and acquisition of data from a crime scene, it is imperative to first establish a clear and concise definition of what constitutes a crime scene. According to the definition of Olsson and Kupper (2017), crime scenes are designated as the physical site where a criminal act has taken place or where there is a reasonable suspicion that a criminal act has occurred. A site of criminal activity may also serve as a point of origin for further criminal investigations, as per source (Olsson and Kupper 2017). The initial responding officers are the only individuals who have access to the crime scene in its unaltered condition. Typically, initial responders comprise law enforcement officials, firefighters, or emergency medical services personnel. According to Miller et al. (2002), the initial actions taken at the crime scene are critical in determining the success of the investigation. Prior to proceeding with the subsequent phase of the inquiry, it is imperative that the initial responding law enforcement personnel meticulously document any modifications made to the crime scene, including the relocation of any items. Subsequently, the forensic examination of the crime scene commences (Olsson and Kupper 2017).

1.2.2 Forensics

Forensics refers to the practical implementation of forensic science, which is a comprehensive field of science utilised to aid judicial actors in their decision-making process (Roux et al., 2012). The field of forensic science is primarily focused on the application of scientific, technological, and medical principles. Examples of fields that can be included are biology, chemistry, physics, and information technology (Roux et al., 2021). Forensic science plays a crucial role in aiding law enforcement officials in their investigative procedures and determinations (Council, 2009). To achieve this objective, researchers focus on leads that arise from criminal activities and the characteristics of these leads. As a result, it is utilised to either corroborate or contradict hypotheses related to a criminal act. The tool in question may additionally serve the purpose of reconstructing either the crime scene or the events that transpired therein (Valjarevic et al. 2015).

1.2.3 Investigation Process

The primary objective of the inquiry is to ascertain whether an unlawful act has been perpetrated and to determine the modus operandi of the offender (Valjarevic et al. 2015). The initial stage involves a comprehensive examination of the crime scene or a preliminary inspection conducted by the primary responder. The forensic investigator is provided with a detailed walkthrough of the crime scene, which is simultaneously recorded through various means, such as instant photography (Lee et al., 2001). The initial responder provides an account of their discovery of the crime scene and the condition of any injured parties present, which have since been relocated. According to Olsson and Kupper (2017), it is imperative to carry out all tasks in a systematic manner. To illustrate this point with respect to individuals who have sustained injuries, one possible approach would be to systematically document their physical condition, commencing with the head and proceeding through each anatomical region, culminating with the feet. The ultimate stage of the forensic investigation procedure involves the reconstitution of a criminal act. According to Miller's explanation (Lee et al., 2001), the primary focus of a crime scene investigator is to determine the modus operandi of a crime, rather than the identification or individualization of the evidence. Consequently, in a CSI, the question of 'how?' holds greater significance than the question of 'who?'.

1.2.4 Forming Hypotheses & Testing Them

The Swedish National Forensic Centre's (NFC) evaluation of forensic findings is based on a methodology that compares two hypotheses. One is the primary hypothesis, which is contrasted with the supporting evidence. For instance, the secondary hypothesis could be "the blood is from a third party who is not present at the scene" if the primary hypothesis concerning a piece of evidence or trace is "the origin of the blood is from the alleged perpetrator". Therefore, the primary theory focuses on the trace's point of origin. The supplementary hypothesis, therefore, has a different starting point. As a result, theories are developed and then put to the test using forensics (Valjarevic et al. 2015).

First, it is assumed that the basic theory is accurate. The blood must match the claimed offender if the main hypothesis is correct if we employ the same hypothesis as before. Then, it is presumed that the second hypothesis is correct. It is more likely that the blood did not come from the claimed offender if the secondary hypothesis' likelihood is higher. Since it is difficult to obtain accurate values, a scale is utilised instead, as indicated in (Valjarevic et al. 2015). These kinds of theories are regularly developed throughout the crime scene investigation. In the end, hypotheses are either proven correct or incorrect, leading researchers to new lines of inquiry (Valjarevic et al. 2015).

1.2.5 Documentation & Forensic Record

There are numerous actors involved in many investigations who need to exchange information. A record is made to make information exchange easier. It describes the crime scene and contains expert results and their contributions. The basic goal of the record is to support and establish hypotheses. One of the most crucial resources is a picture of the scenario. A previously unimportant clue can suddenly become crucial as the investigation goes on. The investigation can come to a halt if there is no image of the lead. Recording the original crime scene on film has significant value as well. It can be used to help law enforcement officials, including prosecutors, understand the crime in the same way. It might also prove beneficial for future experiments as the record includes all data pertinent to the investigation. (Valjarevic et al. 2015).

The record is preserved using a program named DurTv. Each case is assigned a unique number (K-number), and potential evidence is divided into "goods and traces," each of which is assigned a number (G-number) for goods and/or a number (S-number) for traces. A so-called B-number is assigned to confiscated material. This results in the useful categorization of all pertinent information (Catrin Dath 2017).

1.2.6 Reconstructions

Crime scene reconstructions use objects to reproduce the incident in its original form (Damelio and Gardner, 2001). It is typically done at the scene of the actual crime to achieve the greatest results. However, if this proves to be challenging, it can also be done somewhere else. Witness testimonies and photos are utilised in the reconstruction. The main goal of crime scene reconstruction is to ensure that the scene remains unchanged before the evidence is gathered (Lee et al., 2001). For instance, if the scene where the body was discovered does not line up with the rest of the evidence, the victim may have been relocated there prior to the first investigation Reconstruction of previous statements involves a more thorough examination and validation. The subject of the interrogation is free to share their first and concluding remarks regarding the incident. They describe how things happened and who did what before the crime and cross-referencing this with past claims verifies it (Agarwal et al., 2011).

Reconstructions of incidents aim to create a play out of the actual things that happened. Based on the current knowledge of the crime, investigators create a script to reenact the events. Almost always, these kinds of reconstructions take place at the location of the crime and the play is recorded and archived. The footage is crucial to the investigation since it gives investigators quick access to information.

1.3 Computer Vision

While humans can swiftly distinguish objects and separate them from the background in the real world, computers often struggle to achieve the same level of proficiency. Humans are also adept at identifying objects by their characteristics, such as whether they are books or tables. Such issues are of significance to computer vision. In essence, algorithms for computer vision aim to emulate human vision (Szeliski 2022).

The following sections highlight relevant computer vision research that can be applied to both forensics and augmented reality. The portions of this thesis are relatively broad and do go far into the specifics of the various solutions because the applications of computer vision techniques are what this thesis is primarily interested in.

1.3.1 Fiducial Markers

In robotic navigation and augmented reality, fiducials are frequently employed. It enables reference points within a scenario. Then, relative poses between a camera and the outside environment can be created using these reference points. Fiducial markers can be utilised in a wide range of applications; hence, there has been a good deal of research in the area; examples can be found in Figure 2.2. These markers are printed, and they are then placed in an environment where their relative position can be determined. Additionally, the majority of fiducials may store data in the form of an integer value within the image. When there are numerous fiducials present in a scene, the integer value can be utilised as an id (Fiala 2005).

The ArUco markers stand out among the fiducials the most (Avola et al., 2016). They can be used thanks to numerous open-source libraries that make generation and detection simple to access. A notable example is the ArUco marker detection API available in the OpenCV Library (Bradski 2000). ArUco markers have the advantage of being less prone to detection errors than competing technologies (Jurado et al 2014). For an illustration of an ArUco signpost, see Figure 1.1.

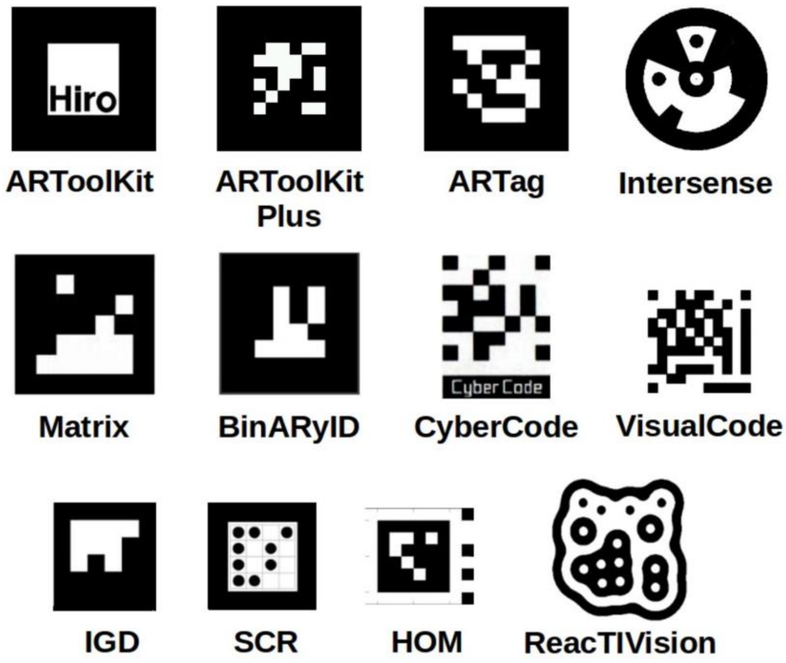

Figure 1.1: Examples of accessible fiducial markers (Jurado et al. 2016)

1.3.2 Image Features

Image features are recognizable, easily distinguishable areas within an image. A set of corresponding locations in various photos can be identified using features in an image. It can be used to determine the location and rotation of the camera pose. The procedure is typically divided into two parts, feature detection and feature matching, to find correspondences. Invariant to scale and lighting, feature detection algorithms locate distinctive places within a picture. These kinds of features frequently appear on items. The following phase involves matching features from two photos using a descriptor for the area around the spot. For many applications of computer vision, correspondences are crucial (Catrin Dath 2017). The SIFT algorithm by Lowe (Lowe 2004) is a feature detection, matching, and descriptor algorithm that is often used. Additionally, it can be found in the OpenCV library (Bradski 2000).

1.3.3 3D Reconstruction

In some circumstances, a point cloud is not sufficient because there will be tiny gaps between the points. Since there is no surface, points are ultimately just points. Instead, 3D reconstruction captures an object's entire shape. Szeliski (Szeliski 2022) outlines a scenario in which 3D reconstruction is used to replicate artwork. 3D reconstruction can be done in a variety of methods. The majority of these techniques, though, fall outside the purview of this thesis.

Therefore, the output of a 3D reconstruction is the main focus. The primary representation of the output, although other options exist, is a 3D mesh.

The employment of 3D Reconstruction technologies has become increasingly significant in the training related to crime scene analysis. Modern 3D imaging methodologies, such as 3D scanners and structured light scanning, have proven to be advantageous for numerous forensic applications. Their non-intrusive nature coupled with their capacity for quick and accurate data collection renders them highly beneficial for gathering essential details concerning the crime scene (Villa et al., 2018, Kottner et al., 2017, Shamata and Thompson, 2018). Various branches of forensic science have embraced these imaging technologies, such as clinical forensic medicine, facial identification (Lynnerup et al., 2009), and the reconstruction of crime incidents (Adamczyk et al., 2017, Raneri, 2018, Bolliger et al., 2012, Buck et al., 2013). Diverse approaches have been utilised in crime scene reconstruction, one of which involves the use of computer-generated imagery supported by game engines for VR display (Trushchenkov et al., 2021). Alternative strategies have amalgamated several technologies including 3D animation, motion capture, natural language interpretation, and computer vision to facilitate courtroom visualisations through VR systems (Ma et al., 2010). More contemporary initiatives have focused on reconstructing crime scenarios in transportation settings using AR tags, particularly for the purposes of forensic training (Tolstolutsky et al., 2021).
However, despite the promising capabilities of 3D scanning technologies in expediting the crime scene investigation process, there are notable limitations regarding the quality of the visual outputs. Earlier scholarly work has pointed out issues such as gaps and inconsistencies in the surfaces and textures generated by 3D scanners (Wang et al., 2019, Tredinnick et al., 2019). Additionally, the constraint of displaying these 3D models on two-dimensional screens undermines the immersive quality of the scanned environments. While some research has attempted to integrate laser scanning with virtual reality tools, there is still a noticeable research gap concerning the integration of AR headsets that offer user mobility.

1.4 AR Associated Technologies

In contrast to VR, AR places graphical elements on top of the real world. The goal of this overlay is implied in the technology's name. Through augmentation, AR seeks to make the real world better, for instance, by providing more information. For image-guided surgery, where clinicians can view an x-ray on top of the body in real-time (Silva, et al. 2003), the extra information can be utilised. To display the graphical elements in the real world, there are numerous options. The Head-mounted AR gadgets are the main topic of this study. Microsoft HoloLens (Bernard 2017) and Magic Leap (Magic Leap 2019) are two examples of this. Both employ a see-through display that lets light into the users' eyes while simultaneously enabling the rendering of the screens with augmented objects on top of the real environments. Contrarily, certain gadgets, such as the Varjo XR-1 (Varjo XR-1 2020) and ZED Mini (ZED Mini 2020), use cameras to record the environment and display both real-world and virtual objects on standard displays.

1.4.1 Spatial Tracking

Spatial tracking, often known as localization, is a crucial component of many augmented reality experiences. Finding an object's position from an unknown beginning point is known as localization (Ribas et al. 2010). Outside-in or inside-out tracking are the two methods for achieving spatial tracking. Older hardware, like the initial Oculus Rift VR device, uses outside-in tracking, in which the position of the device is tracked by external sensors. Modern technologies, on the other hand, use inside-out tracking and do not need any external sensors. Inside-out tracking essentially uses cameras that can localize the gadget to track its position. The more recent Oculus Rift S, for instance, includes several cameras and does not need any external sensors (Oculus Rift S 2020).

1.4.2 Spatial Memory

The capacity of spatial tracking techniques to identify their surroundings and locate themselves inside a single coordinate system is known as spatial memory. This means that if an augmented reality program uses a point (x, y, or z) while it is operating in an environment, the point (x, y, or z) will correspond to the same location in the real world if the application is run in the same environment later.

1.4.3 Depth based occluding

Despite the possibility of positioning objects in the physical realm, they inevitably obstruct the surrounding environment. Depth mapping is a commonly employed technique to address this problem. The process of obtaining depth information can be accomplished by utilising a configuration of stereo cameras. The depth map provides information regarding the spatial relationship between a point in the physical environment and its distance from the observer. The representation in question can be depicted as an image, wherein the hues of individual pixels are indicative of their respective distances or depths, as noted in reference (Andersen et al 2012). By utilising the depth map of the physical environment, it is possible to apply depth occlusion to virtual objects. In essence, virtual objects positioned behind tangible real-world objects, such as walls, will be occluded by the latter and will not be depicted in front of them. The utilization of depth-based occlusion techniques facilitates the integration of occlusion awareness into AR, as indicated by reference (Aleksander 2018).

1.5 XR in Crime Scene Investigation

Several studies have investigated the use of XR technologies including AR and VR technologies in crime scene investigation training. These studies have examined the effectiveness of AR and VR in improving trainees' skills, enhancing evidence-collection accuracy, and providing realistic training experiences. The following section presents a compilation of some notable related studies in this field.

Cisneros *et al.* (2019), developed an AR-based training system for crime scene investigation and evaluated its effectiveness. The study found that trainees using the AR training system demonstrated improved accuracy and efficiency in evidence collection compared to traditional training methods. The AR application allowed trainees to virtually analyse and document crime scenes, providing them with a realistic and interactive learning experience. This study highlights the potential of AR technology in enhancing the training process and improving trainees' skills in crime scene investigation.

Mayne *et al*. (2020), conducted a study to assess the effectiveness of VR simulations in crime scene investigation training. They developed a VR-based training program that simulated various crime scenarios and allowed trainees to interact with virtual crime scenes. The study revealed that trainees who received VR training showed improved skills in evidence identification, documentation, and crime scene reconstruction compared to those who received traditional training methods. The VR simulations provided a realistic and immersive learning environment, enabling trainees to practice their skills in a controlled setting.

Smith *et al.* (2020) conducted a usability study to evaluate the effectiveness of VR technology in crime scene investigation training. They developed a VR training platform that included interactive crime scene environments and realistic evidence collection tasks. The study found that trainees rated VR training as highly usable and engaging. After completing the VR training program, trainees reported increased confidence in their crime scene investigation skills. The study emphasizes the positive impact of VR technology on providing an immersive and effective training experience.

Golomingi *et al.* (2023) explored the potential of AR technology in forensic investigations, particularly in crime scene documentation and evidence analysis. They developed an AR system that allowed investigators to overlay digital information onto the real-world crime scene, aiding in evidence identification and documentation. The study demonstrated that AR technology enhanced situational awareness, improved evidence collection accuracy, and facilitated collaborative investigations among forensic teams. The findings highlight the benefits of integrating AR technology into crime scene investigation processes. Table 1 displayed below, consolidates essential outcomes and understandings derived from a variety of research works that examine the utilization of AR, VR, and MR in the sphere of crime scene investigation. The table enumerates the authors, their pivotal conclusions, and the distinct technologies implemented in their respective investigations. A column labelled "Other Technologies" is also incorporated to underscore any supplementary apparatus or systems deployed in the research. The table functions as an exhaustive resource, providing a succinct synopsis of each study's impact on the discipline, and facilitating the extraction of meaningful knowledge concerning the influence of AR, VR, and MR in contemporary investigative methodologies.

Table 1.1 Comparison between previous studies

Author	KEY FINDINGS	DEVICE	XR
TEO ET AL. (2019)	Explored Mixed Reality (MR) for remote collaboration, enhancing spatial comprehension.	Microsoft HoloLens	MR
PRILLA AND RÜHMANN (2018)	Introduced MR analysis tool capturing users' movements and interactions.	Microsoft HoloLens	MR
SPAIN ET AL. (2018)	Emphasized human factors research and accessibility of AR devices.	Other AR devices	AR
BROWN AND PRILLA (2019)	Conducted a study on usability of AR devices for remote consultations.	Other AR devices	AR
Speicher et al. (2018)[29]	Developed "360 Anywhere" for multi-user collaboration with 360-degree videos.	NA	AR
KOLKMEIER ET AL. (2018)	Investigated remote MR collaborative systems for real-time expert support.	AN	MR
RÜHMANN ET AL. (2018)	Developed a 3D analysis tool for collaborative support using Microsoft HoloLens.	Microsoft HoloLens	MR
POELMAN ET AL. (2012B)	Introduced an MR system for crime scene investigators to collaborate with remote experts.	Microsoft HoloLens	MR
GEE ET AL. (2010)	Implemented an AR system for 3D annotation of physical environments in forensic investigations.	Other AR devices	AR
MA ET AL. (2010)	Explored 3D animation for accurate crime visualization.	Other AR devices	AR
BOSTANCI (2015)	Emphasized the importance of capturing images and videos of crime scenes for digital evidence analysis.	Other AR devices	AR
STREEFKERK ET AL. (2013)	Developed an AR annotation tool for contamination-free gathering of crime evidence.	Other AR devices	AR
RICE (2018)	Highlighted the value of forensic simulations and crime scene investigations in virtual environments using AR tools.	Other AR devices	AR
SANDVIK AND WAADE (2008)	Explored how AR augments physical spaces through mediatisation.	Other AR devices	AR
LUKOSCH ET AL. (2015)	Introduced a mediated reality system for remote collaboration in crime scene investigations.	Other MR devices	MR
(DATCU AND LUKOSCH, 2013)	Developed free-hand gestures for mobile AR applications.	Other AR devices	AR
(LUKOSCH ET AL., 2016)	Recognized AR's utility for enhancing situational awareness in operational teams.	Other AR devices	AR
(DATCU ET AL., 2014)	Compared situational awareness in AR and real-world environments during complex problem-solving.	Other AR devices	AR
(Zhang et al., 2020)	Discussed the capabilities and specifications of Microsoft HoloLens.	Microsoft HoloLens	MR
(Hammady and Ma, 2019)	Highlighted emerging applications of HoloLens in various sectors.	Microsoft HoloLens	MR
HEINONEN (2018)	Described the wireless headset features and capabilities of Microsoft HoloLens.	Microsoft HoloLens	MR
Rajeev et al. (2019)	Addressed the need for precise localization and tracking in AR environments.	Microsoft HoloLens	MR
Cyrus et al. (2019)	Highlighted HoloLens' accuracy in location information and its use of LIDAR.	Microsoft HoloLens	MR, LIDAR
Cirulis (2019)	Emphasized limitations of GPS-based AR systems and solutions using depth cameras and spatial mapping.	Other AR devices	GPS, Depth Cameras
Blom (2018)	Explored the impact of varying light levels on holographic application functionality in HoloLens.	Microsoft HoloLens	AR

1.5.1 Virtual Reality

Komulainen, (2018) presents a virtual reality setting designed for the purpose of visualising crime scenes. The process of laser scanning is employed to obtain a point cloud representation of a crime scene in 3D, which is subsequently utilised to generate a 3D mesh through reconstruction techniques. Subsequently, criminal scene investigators have the ability to examine the crime scene in a virtual environment. The feature enables the annotation and spatial positioning of virtual objects within the scene. One of the objects that can be utilised for visualisation purposes is a mannequin or ragdoll body, which is particularly noteworthy. Individuals have the option to utilise a variety of instruments, such as measuring devices, to deduce the duration of events that occurred within the given environment. The study conducted by Komulainen (2018) revealed that users encountered challenges when attempting to modify the scene during user testing. Consequently, the establishment of the visualisation proved to be a difficult task for the investigators.

1.5.2 Designing a virtual crime scene experience.

The scholarly investigation conducted by Dath (2017) centres on the user experience in virtual reality crime scenes, with a particular emphasis on design principles and key considerations for effective crime investigation within a virtual environment. The proposal outlines five primary thematic directives which are also of significant importance in the context of AR or VR implementations. They are as follows:

1. The capability to virtually explore or revisit the crime scene from various angles and movements through realistic visualisation under the same environmental circumstances as at the time of the crime.
2. Collaboration and communication can be enhanced by sharing, discussing, and presenting observations and theories with colleagues and other stakeholders.
3. The perception of the initial crime scene may be negatively impacted by a restricted timeframe spent in its vicinity. The shorter the duration of one's presence at a crime scene, the higher the likelihood of encountering difficulties in visually discerning significant objects or circumstances.
4. The utilization of visual representations of research outcomes linked to particular geographic areas, accompanied by comprehensive descriptions of the nature of those outcomes and their associations.

5. The capacity to perceive the interconnection between the crime scene and the discoveries in a comprehensive manner, encompassing the ability to visualise distance and depth, as well as orientation and navigation within the virtual environment.

Based on the five principles of Dath (2017), or rules of thumb, the implementation involves the creation of a virtual environment utilising 360-degree images. Individuals have the ability to navigate their virtual environment through the utilization of a virtual reality head-mounted display. Nevertheless, their ability to observe is limited by the particular visuals. In addition, the investigation incorporates annotations and images that are superimposed to present the evidence and information obtained. The author observes that the virtual presence of investigators cannot replace their physical presence at the crime scene, as has been made evident.

1.5.3 AR related technologies in Crime Scenes

The act of incorporating annotations into the physical environment through the use of a portable display device is denoted by Gee et al. (2010). The placement of annotations is accomplished through the utilization of desktop software that incorporates a map of the surrounding environment. The initial step involves the mapping of the environment, followed by the utilization of software, and subsequently, the commencement of visualisation. One intriguing feature of the annotations is their ability to be inserted into images captured from the surrounding environment. Upon revisiting the location, the annotation will remain discernible, even when viewed from different perspectives. The software employs a Simultaneous Localization and Mapping (SLAM) system in conjunction with Global Positioning System (GPS) technology to determine its location.

Jan (2013) presents an annotation system that enables collaborative annotation of a crime scene by users. The utilised hardware comprises a handheld device resembling a tablet, which is equipped with a camera affixed to its rear surface. A study involving users was conducted, and it was observed that the system demonstrated utility. Nevertheless, due to the portable nature of the device, conventional investigative techniques were found to be difficult to implement during its usage. Jan (2013) suggests that the issue in question can potentially be resolved through the implementation of a head-mounted display system. The study presents the development of a head-mounted AR device that is capable of environmental tracking, hand gesture recognition, and network-based display of the environment to other users. The principal objective of their endeavour is to enhance the operational efficiency of initial responders. To streamline this process, communication is conducted via manual gestures, thereby enabling law enforcement personnel to perform other tasks without hindrance. As stated by Ronald (2012), it is possible to apply annotations, conduct bullet trajectory analysis, and implement virtual barrier tape.

1.6 Problem Statement

1. Crime scene training facilities equipped to simulate realistic crime scenes are fundamental in preparing the next generation of investigators. These facilities are designed to expose trainees to different types of crimes as well as to accommodate all trainees to use them, especially cohorts with high numbers. However, the rising costs of these specialised centres cause a substantial problem related to maintenance, equipment, and the need for renovation as it still provides limited simulation compared to real crimes.
2. Time-sensitive evidence, such as biological samples, can degrade quickly due to environmental factors like heat, moisture, and contamination. The degradation of evidence can result in decreased analytical validity, thereby jeopardizing the integrity of the entire investigation. Delay in collecting such evidence may result in compromised samples that can neither be accurately analyzed in the laboratory nor stand up to demonstrate it in a court of law. Incorporating forensic students into crime scene investigations introduces an additional layer of time sensitivity. Students, being relatively inexperienced, may require more time to properly identify, document, and collect evidence. This learning curve, while essential for their educational development, risks exacerbating the time-sensitive nature of evidence collection. Additional time spent on explaining procedures, double-checking work, or rectifying inadvertent errors can make a difference in the viability of crucial evidence.
3. The presence of additional individuals at the crime scene increases the risk of contamination, again affecting the integrity of time-sensitive evidence. Standard operating procedures and strict contamination controls must be rigorously followed, requiring even more time and attention, especially from supervisory personnel.
4. Despite all alternatives of crime simulation to expose students to real crime scenes utilising 3D reconstruction technologies, 3D scanning techniques still have drawbacks. These drawbacks can be visual artefacts and lack of textures. Therefore, producing scenes that

miss significant parts of the scene can conform a challenge for students to investigate properly.

1.7 Research Gap

While numerous studies have delved into the potential of AR in various educational and professional settings, the existing literature demonstrates a notable lacuna in the context of integrating these technologies into the investigative curriculum for crime scene training, especially in Kuwait. Most prior research has either broadly focused on general applications of AR or has addressed specialized domains other than crime scene investigation training. Furthermore, the specific challenges presented by traditional investigative training methods, such as time-intensive processes and the potential contamination of crime scenes, have not been adequately addressed through the lens of AR technology.

1.8 Research Questions

1. To what extent does the integration of AR technology enhance the efficiency of crime scene investigation training for police students in Kuwait?
2. How can combining two different reconstruction techniques for crime scene enhance 3D mesh fidelity and textures in crime scene modelling eliminating holes and visual artifacts?
3. How do young investigators perceive the AR technology and its applications in investigative training practices?
4. How effective is the AR-based training system, rooted in the unique Investigation Process and fundamental investigative practices, in crime scene training?
5. What are the theoretical and practical contributions of integrating AR technology into the domain of crime scene investigation?

1.9 Research Aim and Objectives

The aim of this proposed study is to enhance and transform the training methods for crime scene investigation by integrating AR technology and 3D reconstruction techniques to produce a novel AR Learning Environment, enabling the Kuwait Police Academy – to be extended to any law enforcement agency - to utilise HoloLens 2.0 as an effective tool for aiding crime scene investigation training. Additionally, the study will assess the usability of the designed AR system by a measured model that constructed by incorporating the Technology Acceptance Model (TAM) and Task-Technology Fit (TTF).

The objectives of this research are:

- To conduct a comprehensive literature review exploring the XR systems available for crime scene investigation training and the dimensions of 3D reconstruction scanning for crime scenes, thereby discerning current training solutions.
- To develop an innovative approach via combining two distinct reconstruction techniques to generate a high-fidelity 3D mesh of a crime scene, overcoming of holes or visual artifacts, and enriched with better texture quality.
- To design, develop, and deploy an AR crime scene investigation training system, that addresses the practical standards of the investigation process.
- To construct a novel hybrid theoretical framework that incorporates the Task-Technology Fit (TTF) model and Technology Acceptance Model (TAM) for understanding behavioural intentions towards adopting AR headsets.
- To empirically assess and validate the system and the framework through both quantitative and qualitative research methods.

1.10 Research Outcomes

The proposed research on the AR crime scene investigation training using HoloLens aims to achieve several outcomes. These outcomes are essential for advancing the field of crime scene investigation training and enhancing the effectiveness of training programs. The research outcomes are as follows:

1. Development of a novel hybrid theoretical framework: The research contributes to the literature by introducing a novel hybrid framework that integrate task-technology fit and technology acceptance models. This framework is designed to better understand the behavioural intentions of young investigators towards adopting AR headsets for investigative training. The framework also incorporates elements such as immersion, interactivity, and mobility, relevant to AR headset features.
2. Empirical validation through mixed-methods: The research employs a mixed-method approach involving quantitative and qualitative analyses for empirical validation. A questionnaire administered to 160 police academy students was analysed using partial least squares-structural equation modelling (PLS-SEM). Moreover, qualitative insights were gathered through semi-structured interviews with 11 experts in the field.
3. Novel reconstruction approach: The study combines two different reconstruction techniques. By integrating the advantages of both methods, the resulting 3D mesh not only

possesses high fidelity but also significantly minimizes the occurrence of holes and visual artefacts that are often prevalent in models generated through single-method approaches. Additionally, the integration of the two techniques allows for an enhanced textural quality of the 3D mesh, offering a more comprehensive and reliable representation of the crime scene for forensic analysis. This hybrid approach thereby holds substantial promise for advancing the state-of-the-art in crime scene reconstruction, offering a more robust and enriched model for investigatory purposes.

4. Creation and evaluation of an AR-based training system: One of the practical contributions of this research is the actual development and deployment of an AR-based training system for crime scene investigation. This system, based on high-fidelity 3D scanning and reconstructed crime scenes, was rooted in the unique Investigation Process and fundamental investigative practices.
5. Insights into technology acceptance and usability: The research provides empirical findings on the varying impacts of task-technology fit and individual technology fit on the perceived usefulness and ease of use of AR applications in investigation training. Overall, the research evinces positive inclinations towards usability, user interaction, and contentment with the AR-based system.
6. Contribution to AR training system: The research amplifies the theoretical understanding of the potential of AR learning environments, particularly focusing on Microsoft's HoloLens 2.0 in the domain of crime scene investigation. It combines theories from human-computer interaction, cognitive psychology, and education to create a robust theoretical base for AR learning environments. Overall, the research outcomes aim to contribute to the advancement of crime scene investigation training by leveraging augmented reality technology. The evaluation of existing systems, usability assessment of HoloLens 2.0, design of augmented reality environments, and prototype development of an augmented reality learning environment will collectively enhance the training experience, improve skills acquisition, and promote efficient and accurate evidence collection in crime scene investigations.

1.11 Structure of the Thesis

The thesis is organised into four main chapters to provide a comprehensive exploration of the AR learning environment for crime scene investigation training using HoloLens.

The first chapter, the ‘Introduction’, sets the stage by presenting the background and significance of crime scene investigation training. It introduces the problem statement and research objectives, highlighting the need for innovative training approaches. Additionally, it provides an overview of the AR learning environment using HoloLens, which serves as the focal point of the thesis.

The second chapter is the ‘Literature Review’, where existing knowledge and studies on crime scene investigation training, augmented reality, and virtual reality are reviewed. It examines traditional investigation methods, discusses previous research on the use of AR and VR technologies in training, and explores the usability of AR-based Microsoft HoloLens. This section establishes the theoretical foundation for the thesis and identifies gaps and opportunities for further exploration.

The third chapter, ‘Research Methodology’, outlines the research approach and methodology employed in the study. It describes the data collection methods and instruments used to gather relevant information. The section also provides an overview of the study participants, sample size, ethical considerations, and data analysis procedures. This section ensures the transparency and rigour of the research process.

The fourth chapter,’Capturing crime scene and system design’, delves into the practical aspects of implementing the AR CSI training system. It explores various techniques for capturing crime scenes in virtual reality and details the design and development of the system. The section highlights the integration of HoloLens and other technological tools to create an immersive and realistic training experience for crime scene investigators.

The thesis concludes with the last section, ‘Conclusion and Future Studies’. It summarizes the research findings, evaluates the effectiveness and feasibility of the AR Reality CSI training system, and discusses any limitations encountered during the study. Moreover, it presents recommendations for the implementation and future development of AR technology in crime scene investigation training. This section sets the stage for further research and offers insights into potential directions for advancing the field.

1.12 Conclusion

Crime scene investigation is a critical aspect of law enforcement, requiring meticulous attention to detail, thorough evidence collection, and effective analysis. The use of modern technologies such as AR and VR has the potential to revolutionize crime scene investigation training, providing realistic and immersive learning experiences for trainees.

This chapter has explored the concept of an AR CSI training system, specifically focusing on the utilization of HoloLens. The integration of AR technology into crime scene investigation training holds great promise enhancing the efficiency, accuracy, and effectiveness of the training process.

Through the review of related studies, it is evident that AR and VR technologies have been successfully applied in various aspects of crime scene investigation, including evidence collection, crime scene reconstruction, forensic analysis, and collaborative investigations. These technologies offer trainees the opportunity to practice their skills in a controlled and immersive environment, allowing them to familiarize themselves with real-world scenarios and improve their decision-making abilities.

The proposed research aims to contribute to the field of crime scene investigation training by evaluating existing AR systems, assessing the usability of AR-based Microsoft HoloLens, designing virtual reality crime scenes, developing a prototype of a AR Reality CSI training system, and conducting data collection and analysis. These research outcomes will provide valuable insights into the effectiveness and practicality of integrating AR technology and the 3D scanning and reconstruction techniques into crime scene investigation training programs.

CHAPTER 2
LITERATURE REVIEW

This chapter reviews the extant literature on the use of XR technologies including augmented reality, virtual reality, and HoloLens in crime scene investigation. Through this review, the research questions are being formulated.

Augmented Reality (AR) is a technology that displays holograms and is similar to Virtual Reality (VR) (Lee et al., 2016). The user is totally immersed in VR through the total replacement of the visual environment, AR combines the real world and digital content (Aukstakalnis, 2016). Lukosch et al. (2015a) described AR as a technology that enables viewing and interacting in real-time with superimposed virtual images over the real world. In AR systems, virtual objects are brought to the user as they stay physically where they are whilst having reality augmented. This is because an AR device requires a positioning solution in relation to some reference in the real environment (Kuntz et al., 2018). AR technology can enable the creation of unique collaborative experiences in a way that co-located users can both interact with 3D virtual objects and see them. A live video can be annotated so that a remote user can collaborate with another user at a distance to enhance the face-to-face collaborative experience (Lukosch et al., 2015a).

AR and VR technologies can play a significant role in assisting crime investigators in many ways. They push the boundaries of reconstructing the entire crime scene, as it cannot be done by traditional techniques; instead, a VR-based forensic approach can allow a forensic investigator to create a VR crime scene (Bostanci, 2015, Wang et al., 2019). It provides an opportunity for investigators to have a distinctive walkthrough of the crime scene in a synthetic manner to re-examine the scene (Sieberth et al., 2019). Moreover, it can present narratives, predicted scenarios, and spatial memories in a VR format for juries as visual evidence in courts (Reichherzer et al., 2018, Engström, 2018). Interactive immersive VR systems also assist investigators in determining the course of events (Wang et al., 2019). Moreover, many studies have been conducted in the field of crime scene investigation with the use of AR technology (Linowes and Babilinski, 2017), (Tripathi et al., 2017).

Financing is another issue that may confront HoloLens' real-life application. At approximately $3,000 per set (Fitzsimmons, 2017), which is quite burdensome as each investigator should have a set, relying on HoloLens for all investigations might be difficult for crime scene units. This may be overcome by obtaining light weight smart glasses such as Meta Ray-Ban (Meta, 2023), or via creating a phone-based AR application instead or enabling other officers to use remote assistance on their devices, such as Dynamics 365 which can be used to collaborate instantly without actually having to use the HoloLens. However, all related personnel needs to undergo training in using both the lens and remote assistance in order to ensure the viability of the collected evidence (Fitzsimmons, 2017). Using the study of Poelman et al. (2012a), this will be addressed by using remote spatial interaction with the physical scene offered by mediated reality. Therefore, in this study, we aim to propose A new AR system for effective communication and interaction in visual and spatial crime scenes.

2.1 Review of the related works

As this study deals with the use of AR using Microsoft HoloLens in crime scene investigation, reviewing some works that deal with its use would be worthy of attention. Teo et al. (2019) described mixed reality as a practical solution that can allow people to collaborate remotely through nonverbal communication. Their study focused on the integration of different forms of AR remote collaboration approaches, allowing a new assortment of remote collaboration to expand AR's features and user experience. Teo et al. (2019) presented an AR system that utilised 360 panorama images within 3D restructured scenes. Using a new technique that interacts with numerous 360 panorama fields within these restructured scenes, remote users can switch between various 360 scenes, such as live, past, and present, promoting an improved understanding of space and interactivity.

Similar to Teo et al. (2019), a novel AR analysis device providing 3D reproductions of multiple users in a collaborative setting was introduced by (Prilla and Rühmann, 2018). This analysis noted the importance of information on individuals' movements and behaviour, as well as their interactions with digital objects. The authors recognised the inadequacy of other means of analysis for this purpose and thus developed an analysis tool showing users wearing head-mounted devices. Prilla and Rühmann (2018) stated that MR devices offer unique features, such as advanced means for analysis, not found in other tools.

On the other hand, Spain et al. (2018) identified the main goal of human factors research as the development and application of virtual environments (VE) to enhance human lives across a range of contexts. Brown and Prilla (2019) affirmed the availability and accessibility of AR devices, which Spain et al. (2018) noted. 2D peripherals are usually worn by experts accessing video feeds from 3D head-mounted tools and augmenting them with verbal or digital information. Whether devices applied for these scenarios can also be applied for remote consultations is a relevant concern; hence, Brown and Prilla (2019) carried out a study aiming to re-evaluate this device, leading to findings showing that participants had certain preferences for certain settings despite the evenness of usability scores.

Speicher et al. (2018) claimed that recent studies explore the potential of 360 videos for the collaboration of several users in remote settings. They furthered that these studies were able to identify some challenges concerning 360 live streams, including out-of-sync views. These challenges were dealt with by creating 360 Anywhere, a video framework for multi-user collaboration that supports projected annotations in the 360 streams, allowing a variety of collaborative AR applications not supported on existing devices. Similar to Speicher et al. (2018), Kolkmeier et al. (2018) examined remote MR collaborative systems, which enable experts' real-time support. Kolkmeier et al. (2018) identified core design areas, such as the remote expert's independent viewpoint on the visitor's position and perception and the extent of having the visitor's body represented in the environment of the visited.

Similarly, Rühmann et al. (2018) focused their study on MR which can be used for cooperation support. While investigating collaboration support situations in MR, the authors recognised the need for insights into how technology may be used for working together and came up with a computer-generated 3D analysis tool for MR, which embodied interactive and collaborative support with Microsoft HoloLens. A similar scenario involving the use of MR was examined by Poelman et al. (2012a). In their study, they presented a new MR system developed for the collaboration of crime scene investigators with remote support from expert colleagues. The head-mounted display can carry out map-making on a real-time basis in order for the investigators to collaborate spatially. This is similar to Rühmann et al. (2018) in their use of a 3D analysis tool with interactive and collaborative support. In Poelman et al. (2012a), a crime scene experiment was conducted demonstrating lay investigators collaborating to resolve a spatial problem with experts participating remotely. The findings revealed that the investigation of the physical scene through spatial collaboration with remote experts allowed for tackling current issues at a distance.

Similar to Rühmann et al. (2018), who focused on 3D animation for MR, Ma et al. (2010) carried out 3D animation for accurate crime visualisation, specifically for the benefit of both audience and courtrooms. Using actual data as a basis, the scene was reproduced through forensic animations, showing the activity at various points in time. Computer techniques were utilised to reconstruct crime scenes, thereby replacing the traditional techniques in forensic investigation. The study explored the link between major types of crime in parallel forensic animations and acknowledged that animation with high levels of detail and human characters is suitable for many types of crime and crime investigations although it can be used only on a limited basis in the courtroom.

Moreover, the use of AR technology to investigate crime scenes has been emphasised by many studies e.g., (Rice, 2018, Sandvik and Waade, 2008, Streefkerk et al., 2013). Recent studies revealed that augmented reality technology is capable of supporting distributed teams in the investigation of crime scenes (Poelman et al., 2012a, Datcu et al., 2016, Rühmann et al., 2018). Sandvik (2010) particularly described the term crime scene as a model for understanding and augmenting places.

It is important to capture the images and videos of the crime scene to analyse deeply the digital evidence for potential clues. Bostanci (2015) brought this idea further to utilise the obtained footage to draw the crime scene's 3D model. The results demonstrated that realistic reconstruction can be acquired through advanced computer vision techniques. This same purpose was embodied in the study of Streefkerk et al. (2013), who explored the use of AR annotation tool, whose relevance was grounded in the imperative for forensic professionals to gather crime evidence quickly and contamination-free. This tool enables forensic professionals to practically tag evidence clues at crime scenes and review and share this evidence. Using a qualitative method, Streefkerk et al. (2013) found that annotation could lead to enhanced crime scene orientation, rapid collection process, and reduced administrative pressures. While existing annotation prototypes are technically limited because of time-consuming feature tracking, AR annotation is more promising, useful, and valuable in investigating crime scenes. This is affirmed by Rice (2018) who stressed the increased value and efficiency of forensic simulations and crime scene investigation in virtual environments using augmented reality tools. Through AR technology, along with useful tools and fast access to major databases, law enforcement and investigation personnel can enable marking and highlighting evidence and running real-time tests.

On a similar scale, Sandvik and Waade (2008) examined how places are augmented through mediatisation, describing AR as something that represents processes of mediatisation that broaden and boost spatial experiences. These processes are embodied in users' active participation and the formation of artificial operational environments which are entrenched in a variety of physical and virtual places. Thus, in another study, Sandvik (2010) used the concept of AR to examine the augmentation of places in different ways through various mediatisation strategies. AR denotes the enhanced emotional character of places, including a crime scene, which is an encoded place embedded with certain actions and events that leave various traces to be interpreted and examined. For example, blood, nails, and hair are DNA-coded, in the same way that gun powder and gun wounds are readable and traceable codes. As AR unfolds, the crime scene reveals a narrative that is initially hidden and must be disclosed. The investigative process and the detective's ability to rationalise and interpret enable the crime scene to be transformed from a physical place into a virtual space where the course of events is retold to solve the crime.

Similar to Sandvik (2010) and Sandvik and Waade (2008) who focused on mediatisation in AR, Lukosch et al. (2012a) described an interface-based mediated reality system that supports remote collaboration. In particular, the authors introduced a gesture-specific interface to investigate crime scenes, and through interviews and interactive sessions, such an interface was shown to be effective, easy to use, and easy to learn. Datcu and Lukosch (2013b) offered an even more innovative AR tool for crime scene investigation by using free-hand gestures for mobile AR applications. Proposing a computer vision-engineered model for hands-free interaction in AR, the authors emphasised that the project's novelty was the adoption of a hands-free interaction model, with a particular emphasis on the accuracy of hand-specific pointing system for item selection. The results revealed high pointing accuracy and high viability of hands-free AR interaction. This same efficiency in AR has been earlier emphasised in Bostanci (2015), Rice (2018), and Streefkerk et al. (2013).

Just like other authors in this review, Lukosch et al. (2015b) recognised the usefulness of AR technology for operational teams in the field of security, given the capacity of this technology for quick and adequate exchange of context-related information. Information exchange allows the development of distributed situational awareness and collaboration facilitation. At present, operational teams rely on oral communication for information exchange, which can be ambiguous. Using both quantitative and qualitative assessments, Lukosch et al. (2015a) revealed that a team's distributed situation awareness can be improved through AR. This result was also the same as that of Datcu et al. (2014b), where they compared situational awareness, amongst others, in AR and real-world environments in a collaborative complex problem solution, such as a crime scene investigation. Alternatively, Gee et al. (2010) described an AR system designed for 3D annotation of physical environments, including integration of absolute positioning technology and real-time computer images to produce a virtual 'incident' map. The map was collaboratively developed through the participation of operatives and a remote-control hub. The study showed how the system may be utilised to aid forensic investigators in collecting and processing evidence at a crime scene, which was similar to Poelman et al. (2012a) and Rühmann et al. (2018).

Conversely, aiming to report on the development of handheld AR technology in situational attentiveness and collaborative investigation between teams and remote forensic investigators, Datcu et al. (2016) examined the AR system by focusing on its stability and impact on situational attentiveness and quality of collaboration. It was found that the head-mounted AR system that Poelman et al. (2012a) discussed in their study has certain limitations that are tackled by handheld AR technology. Moreover, the divided attention between smartphone AR technology and the real environment affects situational attentiveness.

On the other hand, Buck et al. (2013) demonstrated how reconstructive issues in the development of patterned injuries were addressed by 3D documentation and data integration. Teo et al. (2019) also demonstrated an MR system that utilised 360 panorama images in 3D restructured scenes, allowing remote users to switch amongst a range of 360 scenes. They described MR as a practical solution that can allow people to collaborate remotely through nonverbal communication. Their study focused on the integration of different forms of MR remote collaboration approaches, allowing a new assortment of remote collaboration to expand MR's features and user experience. In Lehr (2019), the use of AR and MR as up-and-coming tools to fight criminality and terrorism was discussed.

Moreover, VE, VR, AR, and simulations can now be used widely because of recent advances in technology that have made them affordable and accessible to users, practitioners, and researchers alike. In Spain et al. (2018), the main goal of human factors research was to identify how these applications can be developed and applied to enhance human lives across a range of contexts. Brown and Prilla (2019) affirmed the availability and accessibility of AR devices, as Spain et al. (2018) noted, wherein remote experts support people wearing these devices.

After the critical review of all studies that employed AR technology with 3D scanning methods, there are quite a few studies that showed little evidence of achieving high efficiency in the investigation process by aiding investigators after the evidence collection with the privilege of communication, interaction and collaboration among local and remote officers. Therefore, this study attempts to introduce a new form of communicative and collaborative investigation to explore new ways of boosting the level of investigation efficiency and speed in reaching the actual scenario of the crime.

2.2 The Features of Augmented Reality

As this study deals with the use of HoloLens in crime scene investigation, reviewing some works that explore its applications would be worthy of attention. AR remote guidance, which combines reality with augmented reality, virtual reality, and augmented virtuality, can facilitate the transition between these stages. Enhancing reality with artificial images enables easier task performance, particularly when individuals in different locations collaborate with each other. Assembly tasks can be carried out remotely, even if the people involved do not meet each other face-to-face (Ladwig and Geiger, 2018). Similarly, Teo *et al.* (2019) described AR as a practical solution that can allow people to collaborate remotely through nonverbal communication. Their study focused on the integration of different forms of AR remote collaboration approaches, allowing a new assortment of remote collaboration to expand AR's features and user experience. Teo *et al.* presented an AR system that utilised 360 panorama images within 3D restructured scenes. A new technique was also introduced to interact with numerous 360 panorama fields within such restructured scenes. Through this, a remote user can switch between various 360 scenes, such as live, past, present, and so on, promoting an improved understanding of space and interactivity. In Lehr (2018), the use of AR as up-and-coming tools to fight criminality and terrorism was discussed. They even stressed the use of 'smart glasses' that can enable police officers to identify suspects by merely looking at them.
Similarly, a novel AR analysis device providing 3D reproductions of multiple users in a collaborative setting was introduced (Prilla and Ruhmann, 2018). This analysis noted the importance of information on individuals' movements and behaviour, as well as how they interact with digital objects. The authors, recognising the insufficiency of other means of analysis for this purpose, developed and applied a novel device showing users wearing head-

mounted devices. Prilla and Ruhmann added that to their knowledge, the features of AR devices cannot be found in other tools, including the means for analysis.

Moreover, virtual environments (VE), VR, AR, and simulations can now be used widely because of recent advances in technology that have made them affordable and accessible to users, practitioners, and researchers alike. In Spain *et al.* (2018), identifying how these applications can be developed and applied to enhance human lives across a range of contexts was identified as the main goal of human factors research. Brown and Prilla (2019) affirmed the availability and accessibility of AR devices, which Spain *et al.* (noted), wherein remote experts support people wearing these devices. 2D peripherals are usually worn by these experts for accessing video feeds from 3D head-mounted tools and augmenting them with verbal or digital information. Whether devices applied for these scenarios can also be applied for remote consultations is a relevant concern; hence, Brown and Prilla carried out a study aiming to re-evaluate this device, leading to findings that showed that despite the evenness of usability scores, participants noted clear preferences for certain settings.

2.1.1 Collaboration through Technology

Kolkmeier *et al.* (2018) examined remote MR collaborative systems, which enable experts' real-time support. Kolkmeier *et al.* identified core design areas, such as the remote expert's independent viewpoint on the visitor's position and perception; the presentation technology's immersion; and the extent of having the visitor's body represented in the environment of the visitor. In Ruhmann and Prilla's (2018) work, they emphasised that most studies had been allotted to AR glasses to finish tasks, with technology being recognised as having great potential for cooperative tasks. The authors presented a visual search experiment that was carried out in a cooperative MR environment with Microsoft HoloLens tools. In their study of the Microsoft HoloLens AR head-mounted device, Heinonen (2018) presented a discussion of AR and described HoloLens as having two resolution screens and a 360-degree view field and twelve sensors that are used for interacting with the environment. In addition, the device's performance can be compared to a sophisticated mobile device.

2.3 The Use of Augmented Reality in Crime Scene Investigation

Whilst Datcu *et al.* (2016a) stressed the growth of AR into a mature field, the domains of situational awareness and the presence of AR remained lacking in research topics. In order to examine various perceptions of situational awareness and presence in real-world and AR scenarios, a collaborative game was introduced in their study. The game was adopted to model collaborative complex problem solutions and was proved to be feasible, along with questionnaire design, in examining the various perceptions of situational awareness and presence in real world and AR scenarios.

Buck *et al.* (2013) described a tool called GOMATOS, an optical 3D digital technique which is suitable for wound and whole-body documentation for identifying injury-inflicting devices and reconstructing the event. These 3D data were integrated into the dead person's whole-body model. Besides the findings of the body, a 3D documentation of the injury-inflicting devices and the incident was carried out. With this work, Buck *et al.* (2013) showed how 3D documentation and data integration helped address reconstructive issues concerning the development of patterned injuries and how this resulted in a real data-based crime scene reconstruction.

Consistent with the direction of Buck *et al.* (2011), Adamczyk *et al.* (2017a) presented a new 3D generation calculation approach for forensic documentation The purpose of this was to create more insightful and objective forensic documentation. After conducting a series of interviews with technicians, their study suggested that the developed 3D calculation system had considerable potential for becoming a useful device for forensic technicians. In their other study, Adamczyk *et al.* (2017b) mentioned that 3D measurements are becoming a standard forensic process. Through the adoption of 3D measurement approaches, a more insightful investigation can be carried out, helping to demonstrate traces in the entire crime scene setting. In their article, Adamczyk *et al.* (2017b) presented a hierarchical, 3D measurement system for the forensic documentation process. This system mirrored the particular standards in the forensic documentation process, as it was developed to conduct measurements in two documentation phases. The first phase involved the use of a low-resolution scanner with a large measuring volume, which was used to document the whole scene. The second phase involved a more detailed but high-resolution scanner which was intended for areas requiring a more detailed approach. A software platform called CrimeView3D was used to supervise the documentation process.

2.2.1 Microsoft HoloLens as a potential device

Microsoft HoloLens, which was introduced in 2016, correspondingly made apparent transformations in an understanding of AR applications (Hammady and Ma, 2019). HoloLens is a AR head-mounted device developed by Microsoft Corporation, furnished with a holographic processing unit (HPU) for administering real-time data. AR head-mounted displays (HMD) and smart glasses represent immense innovation after the emergence of mobile devices. Its wireless headset constitutes a battery life of around 2-3 hours used actively. Holograms and high-definition lenses, amongst others, are featured in Microsoft HoloLens, allowing the user to see and hear holograms around them. The holographic images of HoloLens assist designers in viewing design results from a 360-degree angle, enabling them to see devices as though they were real (Zhang *et al.*, 2020). In 2017, Microsoft expanded the production of HoloLens to more countries in Europe (Heinonen, 2018).

HoloLens is loaded with a wavelength of diagonal vision field that reaches up to around 35° (30° x 17.5°) with an extremely high resolution. It is equipped with sensors: four cameras designed for locating and positioning, a frontal camera, a sensor with low-energy usage, and an inertial unit. HoloLens' computing infrastructure is where its power principally resides, owing to its vision processing unit (VPU), which allows the user to conduct pose computations that function 200 times better than a conventional software implementation with only very little energy consumption (only 10 watts) (Kuntz *et al.,* 2018).

With HoloLens, the user's experience is significantly improved by its rate of pose computations in its environment. It also has a calibration system which should be performed every time the headset moves around the user's head. The HoloLens headset has built-in sensors to position itself in space, making it a major innovation in the industry (Kuntz *et al.,* 2018).

HoloLens is designed to be shared across multiple devices. This is exemplified by a collaborative design that features a 3D model which is streamed to many HoloLens devices and is projected into the real environment (Newnham, 2017). The sharing HoloLens feature allows multiple users to share data and enables team members to share design results. Through Anchor Sharing, which is one of its features, the communication between designers is enhanced and the efficiency of the team is improved. Moreover, HoloLens keeps objects in their distinctive position and rotation, whereby the stability of holographic objects is ensured. Through World Anchor, which is one of HoloLens' features, the position of the holographic object in the real environment is maintained. When a space anchor is added to a holographic object, the hologram can be accurately restored to its original position in the ensuing steps. After the HoloLens performs a scanning of the space environment, the user can select manual or programmed space anchors. The space anchors' information can be serialised and transmitted to other HoloLens, which can then re-serialise such information (Linowes and Babilinski, 2017; Zhang *et al.*, 2020).

Similarly, virtual prompt icons, which direct the operator to the correct location, are featured in HoloLens. At the same time, the user is prompted with the right tool by loading the virtual model of the tool. HoloLens needs to ascertain the device's location to achieve this function. HoloLens' spatial mapping allows the surrounding environment and surfaces to be identified (Newnham, 2017).

In terms of interaction, HoloLens users can switch between different holographic images. It is important to note that *gaze*, *gestures*, and *voice* are the three interactive channels offered by HoloLens. *Gaze*, which is the initial form of interaction, functions to locate objects and informs the user about the current focus. Conversely, *gestures* are the most vital means to interact. With gaze, virtual objects are selected, activated, and dragged through gestures. Alternatively, the number of UI elements can be reduced, and the UI interface can be optimised through voice commands. This is done by setting a keyword and equivalent behaviours of the application, such that once the keyword is spoken, a corresponding action is invoked (Zhang *et al.*, 2020).

Furthermore, HoloLens is capable of storing several documents, videos, and other files which can be viewed by the user. HoloLens can also install video communication software, like Skype, and allow users to perform real-time video communication on-site. The device's status can also be viewed through a remote system so that problems can be identified, and personnel can be guided to operate (Zhang *et al.*, 2020). The physical HoloLens device is set up by setting up the Windows Device Portal, which allows remote configuration and management of the device over Wi-Fi or USB. The Device Portal includes tools for managing HoloLens and for debugging and optimising applications (Zhang *et al.*, 2020).

Microsoft HoloLens enables the visualisation of AR scenarios (Barba *et al.*, 2019). AR does not simply deal with the combination of computer data and human senses; rather, it is about the combination of real and virtual, real-time interactivity, and 3D registration. Contrary to being pre-recorded, AR is conducted in real-time, which means that combined real action and computer graphics like cinematic special effects are not counted as AR. On a similar note, two-dimension (2D) overlays are not considered AR, which hence denotes that a range of head-up displays, such as Google Glass, are not considered AR. In AR, the app is cognisant of its 3D surroundings and graphics are chronicled in that space (Linowes and Babilinski, 2017).

HoloLens applications have not yet been greatly focused on by many developers because it is still an emerging piece of technology as well as its expensive cost. Nevertheless, some novel applications have witnessed its use in various sectors. An example of this is "HoloMuse", which utilises gesture-specific interactions to engage users with archaeological artefacts

(Pollalis et al., 2017). Another example is the use of HoloLens in medical applications, in which its 3D visualisation is utilised with the use of AR techniques to enable optimised measurements in surgeries (Hammady and Ma, 2019).

With HoloLens, it is important to clarify the concept of MR or extended reality (XR), which can refer to AR, VR or a combination of both into a single application, or a game environment driven and modified by the real environment. It is important to note that Microsoft exclusively utilises MR; however, XR and MR are the same. Microsoft's MR strategy is designed to support a range of devices and applications, from VR to AR (Glover and Linowes, 2019). An AR device necessitates a positioning solution to ascertain its position and orientation in relation to some reference in the real world (Kuntz *et al.*, 2018).

Figure 2.1 shows AR use in Smartphones and HMD. As can be observed, HoloLens falls under large/medium wireless HMD.

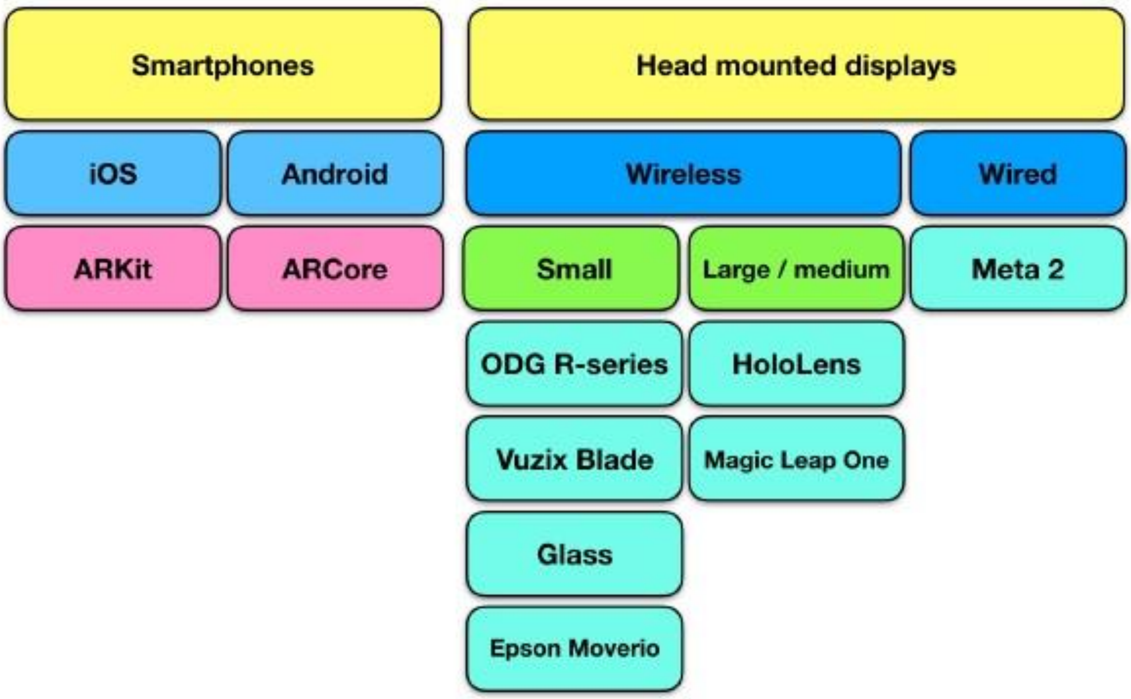

Figure 2.1: AR use in Smartphones and HMD (Source: Heinonen, 2018, p. 4)

2.4 Environmental Aspects of the Use of HoloLens

Rajeev *et al.* (2019) mentioned that the quality of AR environments is based on high-accuracy localisation and user positioning tracking. Developers face the challenge of localising the user based on visible environments. Currently, the Global Positioning System (GPS) is largely used for tracking and orientation, but its accuracy is only about 10 to 30 meters. This is not accurate enough for AR as the precision required by AR should be in millimetres or smaller. Cyrus *et al.* (2019) noted that the HoloLens is highly accurate in terms of location information. In their study, Rajeev *et al*. (2019) proposed an AR-based vision indoor navigation system which can provide accurate localisation and mapping in an environment where GPS is declined. By contrast, Cirulis (2019) stressed that a major disadvantage of GPS-based AR systems is inadequate accuracy for virtual objects.

Likewise, Cyrus *et al.* (2019) stressed that location information is typically used to precisely position holograms within the real environment to the user. Since the information is accurate enough, it can be used to report the position. A range of experiments have been conducted to determine possible errors as a result of vibrations or other effects when the HoloLens is moved. An advantage of the HoloLens is that it can be readily positioned indoors without the need for additional infrastructure while its main disadvantage is its cost (Cyrus *et al.,* 2019).

Moreover, Cirulis (2019) emphasised that changing from smartphone displays to HMD is important in AR, as this will enhance the immersion level of the environment. Although AR will increasingly become significant in the future, there are still factors that limit its use in various areas and industries. Some related problems arise, for which solutions are being developed. For example, it is inconvenient to use AR in outdoor conditions, but there are available solutions to address this, such as Pokemon Go (Pollalis et al., 2017) and Sight Space (Broschart and Zeile, 2015). However, their inaccuracy is very high, preventing the user from moving freely in the augmented environment. Another example is the short range that AR systems can operationally reach. This is resolved by replacing marker-based solutions with depth cameras and spatial mapping (Cirulis, 2019). Cirulis furthered that functionality for indoor and outdoor environments should be achieved for HoloLens, regardless of weather conditions and lighting. However, in actuality, they have very high accuracy, which prevents the user from moving freely. Further projection can be calculated by putting a target 3D model in a fixed position and using data from internal sensors. Similar to Cirulis, Gee *et al.* (2010) performed a study of AR in a crime scene, in which a virtual map is made through the collaboration of many operatives and a remote-control centre. This system covered both indoor and outdoor environments and explained how forensic investigators may be helped by such a system in gathering and processing evidence at a crime scene.

Moreover, Blom (2018) conducted a series of experiments to examine the effects of various light levels on the functionality of a 3D holographic application that operates in HoloLens. Blom found that such functionality was not considerably affected, except when the

surroundings were very dark. In contrast, the visibility of holograms is affected by bright and muddled backgrounds. Therefore, the virtual content's visibility is dependent on the absence of bright light sources in the environment. This is specifically so in outdoor conditions where the weather conditions largely affect the application experience. However, HoloLens devices could decrease poor visibility in fairly dark environments since they have virtual content that gives off its own light (Blom, 2018). This is similar to the claims of other authors regarding the use of AR in both indoor and outdoor environments (e.g. Cirulis, 2019; Gee *et al.*, 2010).
Comparing the Google Tango tablet and the Microsoft HoloLens together, Riedlinger *et al.* (2019) found that in terms of collaboration, users preferred the Google Tango tablet over the Microsoft HoloLens because it felt more natural to interact using the tablet than with HoloLens, although the operation in HoloLens is hands-free and its tracking is stable. Furthermore, obtaining an overall impression is easier when using the Tango tablet compared to a HoloLens device. Riedlinger *et al. (2019)* also observed that users using Microsoft HoloLens found it challenging to accurately position objects in similar surroundings with almost similar features. Since the position of the holographic model relies entirely on the ability of the HoloLens to trace the position of pixels identified by cameras, changes in the environment would result in a drift in the position of the holographic model. This error can be caused by people's movements, materials on site, and other elements that introduce variations in lighting conditions (Gengnagel e*t al.*, 2019). These are similar to the results in Blom's (2018) study which described how muddled and very bright environments affect the visibility of the hologram and how very dark surroundings affect its functionality.
Alternatively, the study of Cyrus *et al.* (2019) found that the HoloLens' light detection and ranging (LIDAR) is typically used as a component of autonomous simultaneous localisation and mapping (SLAM). However, with the use of the LIDAR, the device's scanning of the surroundings usually involves just one plane and can be problematic with glass obstructions, such as a glass door. Along with the correct use of suitable software, the information that the LIDAR provides is accurate, given its high accuracy.

2.5 Conclusion

This chapter extensively reviewed the literature pertaining to the subject under study. It focused on exploring the features of augmented reality and how technology facilitates collaboration in forensic investigations. Moreover, it delved into the application of AR in crime scene investigations, highlighting the environmental considerations for using HoloLens and its significance in crime scene investigation training. Through this comprehensive literature review, the study substantiated the valuable role of HoloLens in enhancing the efficacy of crime scene investigations.

Moving forward, the subsequent chapter will shed light on the research strategies employed to accomplish the study's goals and objectives. These strategies play a crucial role in shaping the investigation and its outcomes, and their detailed examination will provide valuable insights into the study's methodologies.

CHAPTER 3:
RESEARCH METHODOLOGY

3.1 Introduction

The primary objective of this chapter is to expound on the methodology employed to achieve the aims and objectives of the present study, which revolves around the utilisation of Microsoft HoloLens 2 to create an AR application designed to assist the training of the young police investigators. The chapter presents research methods along with the areas to be accomplished including identification of research design, research paradigm, research approach, data collection method, sampling technique, data analysis method, research limitations, and ethical considerations. The theoretical and crime scenario prediction frameworks are also described. The research method used to fulfil the objectives of the research has been discussed. This research is based on both qualitative and quantitative phases. Primary data collection is also defined. Fourteen hypotheses are presented to achieve the goal of the study.

The analysis task encompasses the following key objectives:

- Designing conceptual Augmented Reality crime scenes.
- Designing a prototype AR learning environment App and constructing a graphical user interface.
- Establishing the research model, paradigms and approach.
- Conducting the evaluation of the model and tuning the parameters.
- Integrating the app in HoloLens followed by monitoring and assessing the police training for advanced crime scene investigation in Kuwait.
- Implementing data collection and sampling.

3.2 User-Centred Design

This study adopted a User-Centred Design (UCD) model to better understand user needs and preferences regarding product features. Thus, UCD was applied to better understand crime scene investigation processes and the features of the AR application.

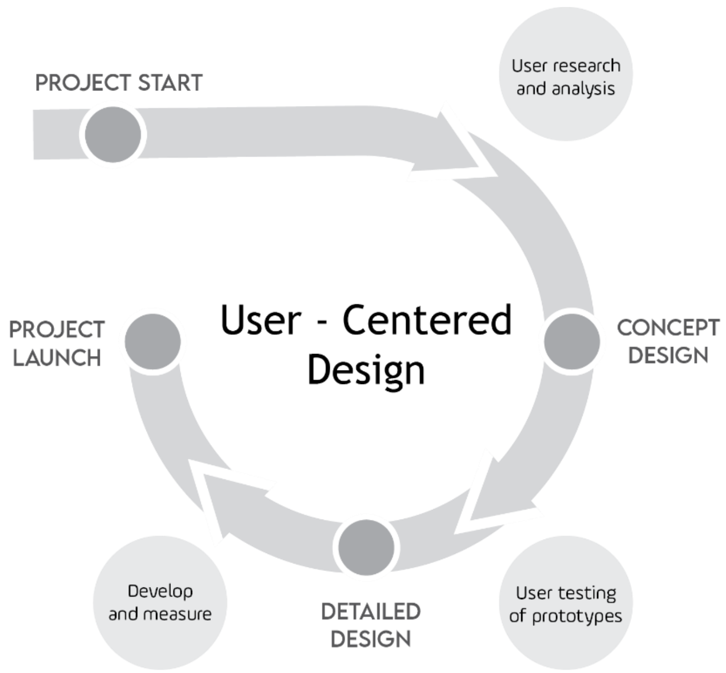

Figure 3.1: User-Centred Approach (Kutsyi, 2020)

As demonstrated in Figure 3.1, it begins with the project's start, which leads to user research and analysis. This is followed by the concept design stage and prototype testing. It is a test build used to set the context and design. After the sample is tested, a detailed design is formed, developed and measured based on potential performance. After the testing and prototyping are completed, the project is launched. The idea is to ensure that a sound sample is tested and refined in the next phase to reach the project launch (Abras et al., 2004).

The purpose of this study is to aid young police officers in being more effective in managing crime investigations via an AR application that uses Microsoft HoloLens 2. The main intent of the project is to improve communications and interactions with investigators so that they can execute highly accurate and efficient investigations. In addition, the project is also set to improve the prediction of crime scene scenarios. This research aims to understand the benefits acquired from the domain of AR applications, which entails updating the archival system via 3D scanning, thereby creating an interactive crime scene so that the investigation can improve and training for police officers in Kuwait can be enhanced.

3.3 Fulfilling the Research Aim and Objectives

Fulfilling the intent and aim of the research involves multiple objectives. One objective is to review the existing literature on AR regarding crime scene investigations. Essentially, the secondary data are acquired via the literature, which is from scholarly sources in books, journals, and other relevant literature. The second objective is to investigate all 3D scanning techniques adopted for reconstructing interior veniues and identify the strengths and weaknesses of the current methods. This is in order to introduce a new method/pipeline to enhance the 3D scans in terms of mesh quality and textures overcoming the current challenges such as holes or visual artifacts. The third objective is to design and develop an application that can be used with an AR headset; this study uses the Microsoft HoloLens 2. The purpose of the proposed system is to train young police investigators, particularly in acquiring evidence and enhancing the efficiency of solving crimes. The fourth objective is to introduce a new framework that integrate the technology acceptance model (TAM) with the task-technology fit (TTF) in order to prediect the behavioural intention of future use by the young investigators. The fifth objective is to assess the proposed framework qualitatively and quantitatively in order to validate the measured model. This was achieved by collecting data from practitioners and experts in the field to better understand the usefulness and ease of use of the system. Consequently, the practical forensic investigation skills for the young police officers will improve. This was done using the TAM, which includes two main factors of technology acceptance: perceived ease of use (PEOU) and perceived usefulness (PU).

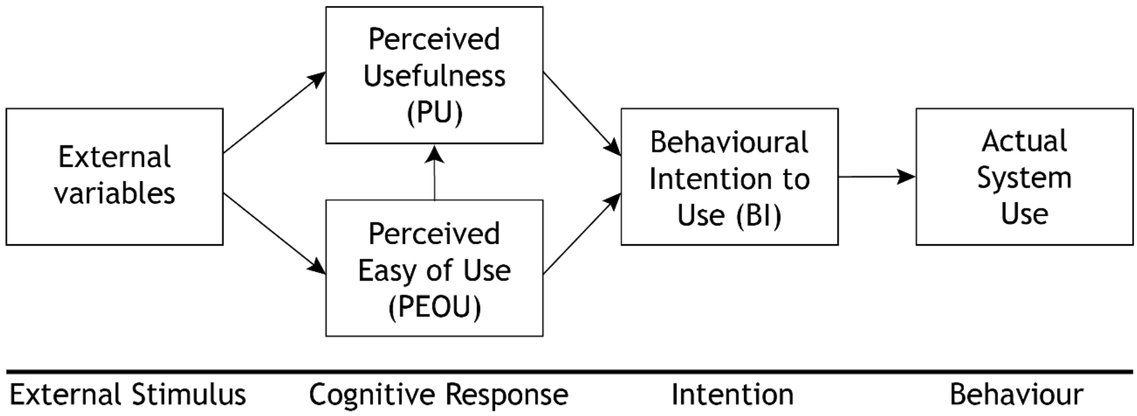

Figure 3.2: Technology Acceptance Model (TAM; Davis, 1989)

According to the model, if users find the technology useful and easy to use, then it may be accepted. As demonstrated in Figure 3.2, external stimuli or variables have an impact on PU and PEOU. In other words, there is an external social element that influences people's perceptions of technology in relation to PU and PEOU. This indicates that the intention to use a technology goes beyond the technology's variables and aspects; in other words, the technology and its features are not necessarily the important aspects that determine its use, as external variables cause the cognitive response. With strong enough external variables, the cognitive response can be there by which technology is accepted; however, it is getting the cognitive response that is the main goal or focus for many when trying to implement a new technology successfully. With a successful cognitive response from an external stimulus, it is possible to see a positive reaction to accepting a technology.

AR is a particular technology that requires some skills to use. Based on this use, it is about understanding investigator responses to AR, which can include whether they consider it easy to use and how useful it may be. However, according to the model, it is apparent that AR needs to have some external variables that then elicit a cognitive response. As this happens, PU and PEOU can be present in the use of AR in the context of solving a crime. If this is not the case, then there is a lack of potential use or consideration in the AR scenario, and it may not be considered a relevant functioning tool for solving crimes.

These two aspects pertain to the cognitive responses of investigators when observing and potentially using AR. This response determines the intention to use or actual usage of the technology, which then results in the behaviour, which highlights what the investigators will do overall with AR technology and whether they will use it or not. The research assesses the usage of the technology, for example, to ascertain its usefulness in communicating crime scene details or for other purposes. This highlights the interest in the practical value of AR technology. Nonetheless, the adoption of the technology is contingent on external factors that influence behavioural intent (BI). Without intent, new technology may not be adopted in the best way for use and productivity, as it is desired overall.

3.4 Extended TAM

The extended TAM (e-TAM) adds to the traditional TAM model by including social influences and cognition. In essence, the consideration of adopting a new technology involves additional social and cognitive processes, leading to the extension of the TAM. As a result, it is apparent that, concerning PU and its determinants, there are multiple usage intentions to consider, especially whether there is an influence on whether a new technology will be used. However, these determinants may influence changes that happen over time rather than immediately, depending on whether a system is increasingly used or not.

According to Barrett et al. (2021), the TAM's acceptance is largely based on how easy it is to use; this is especially true for companies invested in making technology easy to use so that it will be accepted by the masses. The ease of use plays a crucial role in fostering acceptance of the technology. However, the e-TAM emphasizes that usefulness has its own determinants that determine its success. The construction of ease of use incorporates additional elements, and understanding them can significantly enhance user adoption and penetration. As a result, the e-TAM highlights the personal and subjective aspects of considering how easy a technology is to use. Depending on this, a new system may be accepted or rejected. There are multiple determinants to consider regarding ease of use in the realm of cognition, such as quality of output, relevance to the job, and where it can be used. Formally, these are considered perceived interactivity (PI), immersion (IM) and mobility (MOB).

The relationship between BI and the use of technology can be observed through the theory of reasoned action (TRA). TRA aims to assess the connection between attitudes and the actions individuals take. The purpose of the theory is to predict how people will act; ergo, the theory considers the attitudes that exist in people and their BI. Based on these internal and subjective factors, the outcome can be determined, which in this case refers to using technology or not (Sepasgozar, 2022).

Essentially, the main purpose of TRA is to understand why people engage in certain voluntary behaviours. In this case, the behaviour's voluntary aspect outlines the motivation behind any action. To understand this motivation, TRA describes the development of a person's personal attitude, which subsequently influences pertinent actions. In understanding this motivation and the reasons behind it, it is possible to put in place a more robust system to facilitate the acceptance of new and beneficial technologies, which helps everyone involved.

In the context of new technologies, the e-TAM highlights compliance with the technology, considering subjective personal intentions and perceptions. Within the traditional TAM, PEOU and PU are based on mandatory use, not voluntary use; in other words, the non-extended TAM considers situations in which it is mandatory to use technology over those in which use relies on intent and interest (Buzy, 2017). Therefore, the intention to use a new technology voluntarily involves subjective aspects covered by the e-TAM.

According to the e-TAM, technology has the potential to perform a task that can benefit an individual or a group. If an individual can use technology to achieve better outcomes, there may be a strong desire to continue using it. This is especially important if technology elevates an individual's output and image in front of a group. In other words, if a police officer is able to solve crimes better using AR, their output may be higher and of better quality, which will elevate their status in the police station. Thus, the police officer can advance in their career more than from the efforts made. This can add an element of subjective BI to use technology that is not mandatory.

As a result, there is a need to consider adding e-TAM elements that highlight these relevant determinants to observe actual BI. According to Papakostas et al. (2021), output quality is based on a person's perception of how useful a technology is in performing certain tasks. This adds a layer of demonstrability, which is implied in the perceptions of people and by which their positive attitudes can be formed and observed.

3.5 Theoretical Framework: e-TAM Elements

3.5.1 Technology Fit

Task–Technology Fit (TTF). TTF serves as a metric for evaluating how effectively a given technology assists an individual in completing a designated set of activities. It is broadly applicable in contexts where individuals use technology to perform specific tasks (Gikas and Grant, 2013). The concept is characterized by the congruence between the functionalities of the technological device or system and the task at hand, which is pivotal in influencing the results of job performance (Goodhue et al., 2000). The task of helping young police officers resolve crimes is a specific one that has its own needs. This includes using AR to be more effective and efficient as police officers. If the technology is not set up specifically to help with the task, then its usefulness is low. According to Dunleavy and Dede (2014), AR has a variety of uses that create various users and purposes for the technology. Without setting the technology according to the needs of the users, its fitness for the task would be low. Thus, solving crimes has its own specific requirements, and it is up to technology to effectively provide the desired results for a successful outcome.

Individual Technology Fit (ITF). The connection between individuals' involvement and interaction with technologies is frequently linked to their behavioural adaptability to these technologies (Yu and Yu, 2010). The capabilities of these technologies correspond with personal skill sets and the requirements of specific tasks (Wu and Chen, 2017). Young investigators have a method or fit by which AR is used to solve a crime. This entails each officer being able to use the technology individually without barriers. According to Opoku and Francis (2019), having technology that is relevant to each person's needs is highly important for it to be effective. Essentially, there are set procedures that police officers go through in the process of solving a crime, and these need to be facilitated with technology. If the use of the technology does not fit the procedures, there will be potential problems with its adaptation.

3.5.2 Crime Investigation System

Perceived Interactivity (PI). PI denotes the ability of users to instantaneously alter both the framework and content of a mediated setting (Steuer et al., 1995). According to McMillan and Hwang (2002) interactivity is characterized by three principal elements: the direction of communication, the command exerted by the user, and temporal factors. The direction of communication focuses on the computer's role in facilitating human interactions, particularly emphasizing two-way communication. The aspect of user control examines the manner in which humans manipulate computers, with some studies in Human-Computer Interaction (HCI) focusing on human cognizance, while others target the design of the computer (Reeves and Nass, 1996). The temporal aspect, being the third facet, evaluates the speed and ease with which users can navigate within an application. Interactive platforms enable users to function at their own speed and choose their preferred navigational paths (Latchem, 1993). PI also considered one of the core components responsible for whether or not new technology will be used is the PI. This refers to the perception of what is required to manage a task or solve a crime. If there are barriers to entry, then there may be a lack of interest in trying to interact with the technology for its main purpose (Carmigniani et al., 2011). Essentially, AR requires a lot of potential interactions to be used for a specific purpose. Due to the many uses of AR, a level of interactivity must occur for it to be useful.

Immersion (IM). Immersion is a term that is subject to various interpretations within scholarly discourse. Some academics consider it to be a feature intrinsic to the VR system, whereas others regard it as the sensory and narrative responses triggered in a virtual setting (Nilsson et al., 2016). Contradicting the notion of immersion as a subjective psychological experience, other researchers, such as Slater and Sanchez-Vives (2016), assert that immersion can be quantified as a property of a VR system. They suggest that the level of a system's immersiveness can be evaluated based on its ability to emulate the features of another system. For example, a VR system employing a head-mounted display can completely replicate the functionalities of a desktop-based VR system, though the reverse is not possible. While the interpretation by Slater and Sanchez-Vives (2016) offers insights into the technical potential for immersion in VR systems, it does not necessarily account for the sensory experiences of the users or their interactions with the virtual content. Mütterlein (2018) sees these elements as part of a subjective assessment of immersion. These diverse viewpoints underscore the complex nature of immersion, which can be regarded as a technological attribute, a physical sensation akin to being submerged in a fluid such as water, or a purely cognitive engagement, similar to the absorption one feels while reading a captivating novel (Witmer and Singer, 1998, Sherman and Craig, 2018). Also, IM is a key component in actually using the technology for its intended purpose (Opoku & Francis, 2019). In this case, it is about being able to immerse in or use the new technology for the needs of the users. In addition, the technology needs to facilitate the desired output; there is a level of IM in managing its use and relevance overall. With a higher IM, it is possible to fulfil more of the task's requirements, thereby causing the output quality to be greater. If users are able to immerse themselves effectively, there is a chance that acceptance will spread among their peers (Al-Rahimi et al., 2013).

Mobility (MOB). MOB denotes the capacity of mobile technology for ubiquitous use (Shin, 2012). It outlines the sense of freedom users experience as they move between different locations while using their mobile devices (Verkasalo, 2008). In the context of this research, it is specified as "the extent to which users are cognizant of the spatial settings of crime scenes." Mobile devices are particularly effective in instilling a deep sense of convenience and immediacy in users, fostering the belief that they can quickly, easily, and promptly retrieve information (Kynäslahti, 2003, Huang et al., 2007). One academic posits that the ability to access content and services at any time and any place is the most salient characteristic of mobile-based ICT [89]. MOB is becoming a prominent force with modern technology (Altin Gumussoy et al., 2018). In this case, it is about being able to use the technology whenever and wherever it is desired. Currently, smartphones have become a prominent force in the MOB space (Altin Gumussoy et al., 2018), and technological items are now able to provide almost the same functionality as computers while users are on the move. The MOB of technology facilitates greater use and relevance for a variety of purposes as a means of ensuring a successful outcome.

3.5.3 Perceived Usefulness (PU)

PU is characterized as " the degree to which a person believes that using a particular system would enhance his or her job performance" (p.320) (Davis, 1989). The model for technology acceptance suggests that the main impetus for the adoption of information technology lies in its perceived usefulness (Cheung et al., 2011, Ngai et al., 2015). Davis (1989) argues that should users perceive technology as advantageous in enhancing their occupational performance, their inclination to utilize it is likely to rise. PU is one of the core aspects of TAM, and it relates to the perception of how useful a technology is (Mutahar et al., 2018). If a technology is not perceived as useful, there may be a lack of intent or interest in using it. Thus, usefulness is an important aspect of even considering a technology, as, without it, a person may have no intention of trying it, let alone accepting it.

3.5.4 Perceived Ease of Use (PEOU)

The concept of PEOU is articulated as “the degree to which a person believes that using a particular system would be free of effort” (p.320) (Davis, 1989). This is intended to minimize cognitive workload (Alharbi and Drew, 2014). Venkatesh (2000) demonstrated that the principal psychological belief that affects an individual's willingness to adopt a given technology is its perceived ease of use. Cheung et al. (2011) emphasize that numerous academics consider this to be an important determinant in shaping people's views towards technology. Additionally, it is recognized that the perceived simplicity of a system significantly influences attitudes (Lu, 2014). According to Alsamydai (2014), the ease of use of a new technology depends on an individual’s existing perceptions or frameworks. In other words, how is the technology seen in terms of whether it can be easily used or not? With PEOU, it can acquire mass interest or not, with the potential to become the new standard.

3.5.5 Behavioural Intention (BI)

BI is the final aspect of the TAM and refers to how, if a technology is found easy to use and relevant, it can eventually create a BI that determines whether or not it will be used. Essentially, the TAM highlights all the important features through which BI is formed.

3.6 User Research and Analysis

The methodology of the present study involves the research and analysis of data gathered from the target users. Thus, this study recruited junior investigators from the Kuwait police. The idea is to focus on a practical approach that includes investigators to gain an understanding of how the application can be used in the real world. This takes a case study approach and includes actual cases or junior investigators. According to Crowe et al. (2011), case study methods take a look at practical examples to integrate theory and concepts into real-world concepts. As a result, the AR application is a concept that benefits from a case study approach that considers its real-world potential.

3.7 Concept Design

The concept design requires acquiring data to understand the practical efforts and training needed for investigation (Keinonen, 2010). Based on this, the AR application can be formed and provide real-world scenarios in which the relevance of the application is seen as being used by investigators. The purpose is to understand the use of the application and how it can assist in the investigation of these crimes.

3.8 User Testing Prototypes

After the concept design, prototypes need to be tested with relevant experts in the field, such as senior police investigators and experts in Human-Computer Interactions and User Interface (UI)/ User eXperience (UX). Feedback from experts is used to improve the design, which entails changing the design, resolving any glitches, and improving the user experience (Rocha Silva et al., 2019). Finally, the development and measurement of the application require test users for over 100 young police investigators to ensure that it is effective in its purpose.

3.9 Detailed Design

There is a unique framework for predicting crime scenarios and understanding the process of digital investigations (Figure. 3.3).

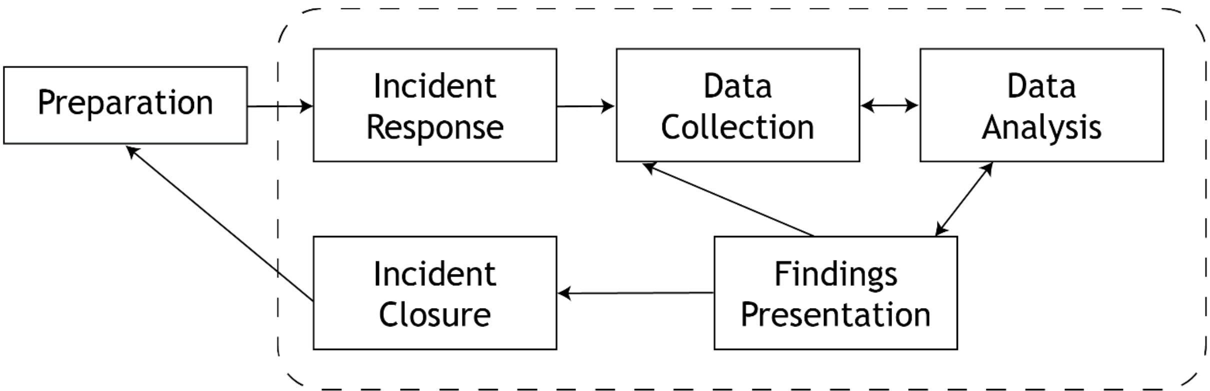

Figure 3.3: Unique Investigation Process by Beebe & Clark (2005)

In the system and its application, there is preparation for and a response to the incident. The data are then collected, presented and analysed. The incident is then closed after it is completed. To complete the research, there must be consideration of the literature regarding crime scenario predictions; this is needed in order to conduct the research. Additionally, this entails developing pertinent questionnaires and interviews.

3.10 Forensic Investigation Framework

The principles of forensic investigation must be considered, with a primary focus, on conducting an efficient and effective investigation. It is imperative to consider the processes and procedures needed for a proper forensic investigation. This is especially pertinent for the model, which uses digital evidence. This integrates solutions that are preventive in nature. The idea is to ensure that incidents related to security are managed, which constitutes the preparation phase per the model. There is then the incident response phase in which the data are collected and analysed. Within the analysis, data interpretation was considered in the investigation model. It is possible to modify this model effectively to facilitate conducting investigations in the best manner. The model ends with a procedural investigation, which is done at a high level. These steps are the phases of the model. One of the key benefits is the development of the work, which is then verified at the end. The suggested change is to add finding clues in the middle, after the incident response.

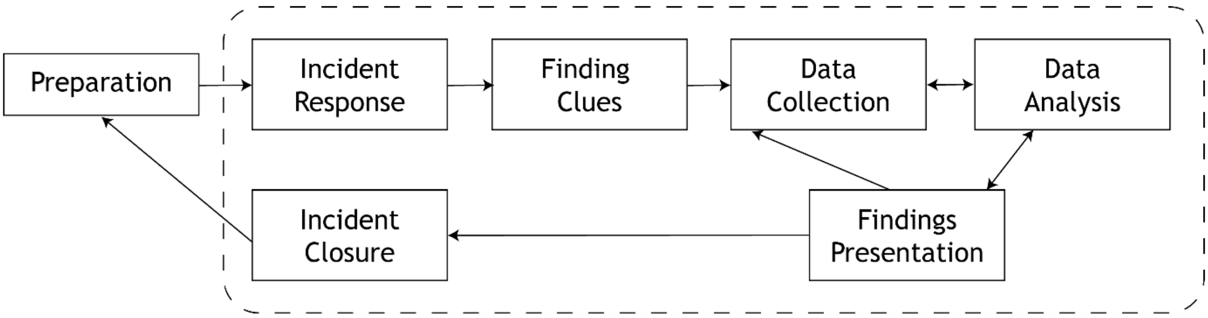

Figure 3.4: Unique Investigation Process

The intention is to overcome the model's disadvantage, which is that it does not include the appropriate level of permanent feedback. Essentially, the idea is to solve the crime in a manner that is closer to perfection, with the right improvements in place. This is the main reason it can be a systematic focus through which management is effective at any crime scene. With these clues, there is constant standardisation in the workplace. Furthermore, there is constant growth in the data, which increases the risk of not processing it effectively or having it tampered with. An example is the process of finding clues at a crime scene. This is an important part of the investigation to achieve success; however, issues may arise that make it important to minimise negative outcomes. Thus, the variable can improve the digital data needed to acquire valid evidence. Finding clues is an important step that is imperative to ensure accuracy in the later stages of collecting data and then analysing it.

The process of predicting a crime can be quite complex and it requires an understanding of the motives of the criminals and what they might potentially do. Rational cause theory is about understanding the motivation that leads to a crime being committed. This refers to a decision made purposefully so that there is some form of potential gain, such as status or resources. With regard to the crime, it includes the type, location and finally the target. In predicting crime, it is important to understand these aspects, as seen in the theory.

Technology can be used to predict crime. The purpose behind the use of AR is to create a scenario in which the surroundings can be analysed to understand crime and predict it. The visual world can be processed with a variety of AR applications, including surroundings, faces, number plates, objectives and more; each of these requires finding clues and processing the data. The 3D imagery of the AR system can help with a variety of different processes to find clues and acquire data. The results of a computer's potential to be found at a much faster rate compared to traditional methods are due to technological assistance in solving and predicting crime.

According to Lukosch et al. (2015), machine learning (ML) is a major application in the use of AR to predict crime. ML is an application in which the technology system learns and adapts by learning from previous experiences and building upon them. ML has the potential to go beyond its existing programming.

ML can specifically help in the data analysis phase of the Unique Investigation Model. The technology is able to conduct complex operations to discover patterns with valuable data. ML can be supervised (i.e. using a predefined feed for training) or unsupervised (i.e. allowing the machine to figure it out on its own). The concept here can be further outlined in systems theory.

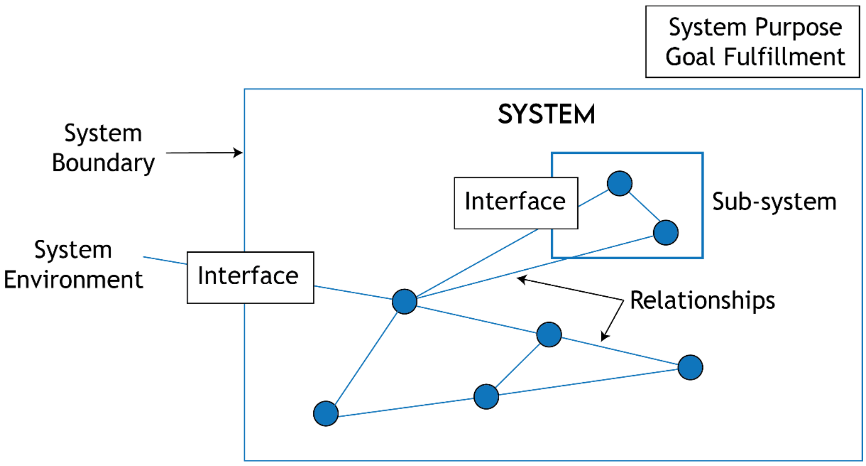

Figure 3.5: Systems Theory (Matook & Brown, 2008)

As demonstrated in Figure 3.5, there are a variety of interrelated parts involved in systems theory, and these parts work together based on their structure, which entails time, space, environment, and purpose. As the system functions, it expresses the desired result; for this scenario, it predicts crime. Essentially, these relations are potentially complex and form the entire system. As the system is made and developed, there are interactions with several different elements, which then cause the final result or system to emerge.

According to Mahmud et al. (2016), crimes can appear to be unpredictable; at the same time, as new crimes are committed, there is a need to try to improve predictions, regardless of how difficult they may be. Overall, the process of crime-solving can be complex, especially with the advent of technology, as criminals are using it more effectively. This requires more effective tools, per systems theory, in which an interface and different systems work in tandem with one another. With these new tools, it is possible to continue improving the efficiency of solving crimes. For instance, technology has improved the ability to travel over large distances, which shows the potential for strong output; similarly, new technology has the potential to improve how crimes may be solved. This makes it important to consider updating the process of solving crimes, especially when there is a tool that can make it better or easier to do so.

According to Rampolla and Kipper (2012), if AR technology can accurately predict and solve crime, then it is possible that more primary resources will be utilised; this entails more people, funds and much more. The idea is to showcase it effectively so that there can be a potentially successful outcome that benefits law enforcement in dealing with crime. With more crimes being solved using the system, it is possible to create a database and use it to expand upon the existing repertoire of knowledge to solve crimes, especially for junior investigators. As a result, if junior investigators start using technology early, there is the potential to be even better in the future by gaining more familiarity with technology and its advancement. In other words, as junior investigators become more proficient with new technology, there is an incentive to include updates that can further improve output. This provides the overall interest in trying to have a strong BI to use any useful technology to improve the overall output. It then creates a beneficial effect whereby there is constant improvement in the use and development of technology. Essentially, once a technology is adopted and used, the market will create further iterations where they may not otherwise occur. Thus, it is important to consider any productive technology, such as AR, when solving crimes.

3.11 Research Methods: Mixed Methods

This study uses a mixed methodology, including interviews and questionnaires, to facilitate a combined qualitative and quantitative study (Stahl et al., 2019). As the research is qualitative and quantitative in nature, it uses interviews and questionnaires.

3.11.1 Interviews

According to Trainor (2013), an interview is a conversation in which one party asks the other questions. The parties involved include the interviewee who is being interviewed and the interviewer who is conducting the interview. In a typical interview, the interviewer asks questions to which the interviewee responds. For this study, interviews were conducted with experts to provide qualitative feedback on the topic of using AR to solve crimes. According to Adhabi and Anozie (2017), qualitative feedback is in-depth in nature, which provides more details about the how and why related to the topic; in this case, it is about how the AR system can be used to solve crimes better and why it can be effective overall.

The interview type was semi-structured and combined structured and unstructured types. In a structured interview, the questions are predefined and set before the session. According to McGehee (2012), a structured interview has benefits, as it sets the direction of the session, which can prevent deviation from the topic and is based on the aim and objectives. However, an issue with structured interviews is that they can be limited in what they ask without exploring new ideas and concepts. Thus, it is important to add unstructured aspects to the interviews. The unstructured aspect allows for openness in the interview session so that the interviewer can follow up on new topics discussed; in other words, if an interviewee brings up a unique concept, then the interviewer can ask for elaboration or follow up on it, providing a highly needed level of flexibility. This is important for this study because the AR technology studied for use in investigations is new and highly experimental.

11 interviewees were experts in the CSI field and senior investigators. They were able to comprehend the value of AR technology for their use and provide insight into the relevance of the technology and in what manner it could be considered. These insights are valuable for completing the aim and objectives of understanding the practical use of technology. The interviews included open-ended questions to acquire qualitative data, which offered in-depth insights into using AR technology to conduct investigations.

3.11.2 Questionnaire

The quantitative data were collected via questionnaires. According to Patten (2016), questionnaires are tools that include questions intended to acquire pertinent data from participants. Questionnaires can be written or oral. In this study, the total number of participants was 160. One of the main benefits of using questionnaires over interviews is that they can be conducted with many more participants compared to interviews. As interviews are limited in the number of people who can participate, questionnaires have the potential to collect data from many respondents due to their quick and easy nature. In other words, questionnaires can be deployed to many participants to acquire a significant amount of data, especially statistical data that can be processed. For this research, the questionnaires had closed-ended questions, with some open-ended ones near the end. The questionnaires were provided to experts and junior investigators. This was performed with the intent of acquiring practical insights into the use of AR technology to investigate crimes. As the junior investigators were new to the field and proficient with technology, they were able to provide details about the effective use of AR technology with the intent of trying to garner an understanding of its use and relevance.

3.12 Primary Data Collection Process

Primary data were collected from the study participants. In this case, it included experts for interviews and junior investigators for the questionnaires. However, prior to engaging in any research, it is imperative to ensure that proper ethics are followed. There were a few ethical considerations in this study. One was that the participants were of legal age to consent and were fully cognizant of the research. Thus, participants were provided with complete details or a participant sheet that allowed them to read what the research was about and the main objectives that were being fulfilled. The participants also had the option to ask the researcher any questions. Once it was clear, the participants were asked to sign the thesis, opt into the thesis or reject participation. The participants also had the option to leave the study, even if they had agreed to enter, before the analysis phase.

Participant recruitment efforts focused on contacting universities and investigation departments. After consent was given, the researcher asked experts from universities and investigators in the police department to participate in the interviews. After consent was obtained and the participant sheet was given, the researcher strongly emphasised that privacy would be assured and that no personal identifiers would be used in the study in any way other than to verify the background of the results.

After acquiring consent, participants were divided into two main groups: those for interviews and those for questionnaires. The interviews were merely asking questions in a semi-structured format. For the questionnaires, this was a little more complicated. The questionnaire was divided into sections based on the e-TAM framework, which included TTF, ITF, IM, PI, MOB, PEOU, PU and BI. The junior investigators were asked to answer each of the different blocks in the questionnaire.

Prior to answering the questions, the junior investigators were given a quick demonstration of AR technology, which was brought to their workplace so that they could see how it was used and offer their thoughts about it. After gaining some experience with the technology, they were able to provide effective answers to the questionnaire.

For the interviews, the experts from the police academy met at a wide venue to trial the system. These experts are tasked with undergoing training on the Microsoft HoloLens, a AR headset, with each training session estimated to last around 10 minutes. Subsequently, they are afforded the opportunity to interact with the system, mirroring the conditions set for the first group. Post-interaction, they are engaged in interviews comprising open-ended queries. The objective of conducting these interviews is to ascertain both the appropriateness of incorporating a virtual crime scene into the augmented reality training framework and the system design's usability. Additionally, the interviews aim to delve into the proper sequence of investigative procedures aligned with established police investigation protocols. The inquiry further explores the system's capabilities for information gathering and evaluates its potential as an instrumental resource for augmenting crime scene investigative methodologies. The duration of each interview is approximately 10 minutes.

Ethical protocols ensured that the participants were treated with respect and that the time was adhered to. Participants were free to answer or not answer any questions as desired. The participants were also informed that the session would be recorded and transcribed while ensuring privacy. If any answer was not legible, the researcher explained that they would follow up to make sure the answer was understood or that it would be discarded if no correct version was found.

At all times, the participants were treated properly, and things were done according to their comfort. The researcher ensured full transparency and made it possible for participants to change interview times or opt out of the research. Privacy was maintained by locking away personal data during the analysis phase. After the analysis was done, the personal data were destroyed to further protect privacy and to ensure that there would be no leaks at any point in the research, as they were handled only by the researcher.

The combination of the interview and questionnaire methods formed the data collection process. The combination of these elements fulfilled ethical obligations according to university guidelines. In all cases, the participants were of legal age to consent and were fully aware of all aspects of the research. They were also given full autonomy to leave the research at any time or not answer any questions as desired. Finally, the participants' privacy was also completely protected by locking up the data and then destroying it once the research was completed. The combination of these efforts fulfilled the ethical requirements of the university.

3.13 Risk Analysis

- In case of a HoloLens Equipment Failure, officers will not be able to digitally map the crime scene in 3D. The chances of equipment failure are low, but as a failsafe, a number of headsets will be available for backup.
- In case of a Denial-of-Service Attack (DDoS) on the Cloud Repository, Officers may be unable to access records and their communications and this could be compromised. To prevent this, we will implement a strong firewall with encrypted data transfer using secure servers with strong authentication for effective mitigation.
- We understand that police are involved in close combat with criminals, so damage to the glasses is always possible. An extra set will be provided.
- In the case of Internet Service Problems, there will be communication problems between the cloud servers and onsite equipment. Mobile Wi-Fi stations will be provided to all officers to ensure smooth communication over the internet, even on hard terrains.

3.14 Research Model and Hypotheses Testing

The proposed research model is based on the theoretical foundations of the TAM. The relationships among the constructs in the proposed framework are shown in Figure 3.6. The underlying assumption is that the BI to adopt a crime investigation AR system is predicted through PU and PEOU, which are determined through TF variables and the AR system. The constructs and justifications for the suggested hypotheses are described in the following subsections.

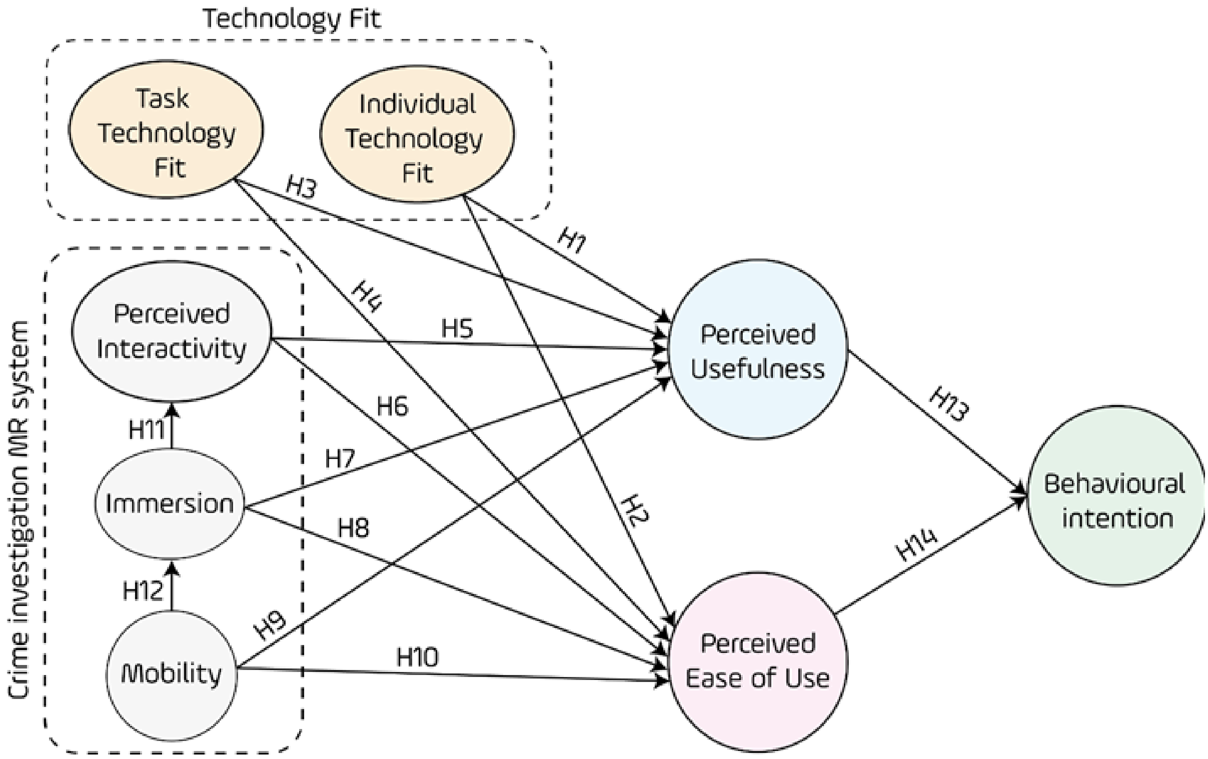

Figure 3.6: Proposed Framework

3.14.1 TTF

TTF and PU.

According to Furneaux (2012), the relevance of technology to a particular task is what determines its fit or use in any scenario. Thus, if the AR can actually perform the task, then its perception of usefulness can cause penetration into using the technology. Vanduhe et al. (2020) considered how TTF and PU are linked and showed that PU is responsible for creating the social recognition of any technology, which then determines the potential TTF. According to Bing et al. (2017), TTF has a significant impact on PU. Many previous empirical studies (Kim, Suh, Lee, & Choi, 2010) have suggested that the perception of whether a particular technology fits well with the present values of users can be the basis for forming perceptions of actually using the technology. Previous scholarly investigations, including those conducted by Pal and Patra (2021) and Jung et al. (2020) have determined that the congruence between technology and users' existing values, particularly in terms of perceived ease of use and perceived usefulness, shapes their attitudes towards the adoption and utilization of said technology. These studies further suggest that the compatibility between the technology and the task at hand affects both perceived ease of use and perceived usefulness. To put it differently, a higher degree of fit between the task and the technology increases the likelihood that users will perceive the technology as both easy to use and beneficial for the specific task. The attributes of a technology are also instrumental in the efficacy of VR headsets. Existing literature posits that the perceived value in the context of the study, which in this case refers to CSI training through AR devices, relies on users identifying compatibility between the task and the technology. The propensity for users to voluntarily adopt AR devices and their corresponding applications for training is likely influenced by the degree to which the task is in harmony with the technology, thereby affecting their perceptions of the ease of use of AR headsets and applications. Moreover, empirical results have demonstrated that PU is affected by TTF; that is, when the fit between the task and technology is higher, users perceive the tool as easier to use and more useful for that task.

H_1: TTF has a significant influence on PU of AR in CSI training.

TTF and PEOU. Initial investigations by Wu and Chen (2017) have suggested that a positive correlation exists between an individual's compatibility with technology and their perception of its utility and user-friendliness, specifically in the context of Massive Open Online Courses (MOOCs). Moreover, the congruence of technological functionalities with users' necessities has a noteworthy impact on their attitude and utilization of the technology. Multiple studies corroborate that beyond aligning technology for a designated task, it is imperative to harmonize the technological features with the specific needs of the users (Goodhue and Thompson, 1995, Parkes, 2013, Liu et al., 2011, Yu and Yu, 2010, McGill and Klobas, 2009). Consequently, technology that is customized to align with individual learning styles and abilities is more likely to be adopted and effectively employed. In this scholarly work, ITF is conceptualized as the alignment of online technological features within the AR applications' platform to the distinct learning approaches of individuals. When robust compatibility exists between the technology and the learning strategies of users, the propensity for the technology to be engaged with is elevated, as delineated by Cane and McCarthy (2009). Howard and Rose (2019) mentioned that PEOU can often outline whether the technology will be accepted by the public. AR has many different uses in many different fields. Its use and ease in the specific context of solving crimes can be a potential boon for police officers. Thus, the potential for its acceptance is based on whether police officers find it easy to use. According to Bing et al. (2017), TTF has a significant impact on PEOU. A study by Ishfaq and Mengxing (2021) in Pakistan highlighted that internet-based services showed that TTF does have an impact on PEOU; in this case, TTF was responsible for setting the conditions for PEOU to occur in the first place. As a result, if technology is seen to fit a task or to have a TTF, then it lays the foundation for PEOU to occur, which makes it a positive correlation. This can elucidate how a technology that is useful for a task can help improve the intent or motivation for PEOU. Essentially, there is a task to be fulfilled; if the technology can complete a task, it is then considered easy to use. the This demonstrates a link between technology's ability to finish a task and the importance of being as easy to use as possible. Overall, this denotes a functional aspect of the technology, where its use is considered in terms of ease of use.

H_2: TTF has a significant influence on PEOU of AR in CSI training.

3.14.2 ITF

ITF and PU. Past scholarly investigations, including those by Pal and Patra (2021) and Jung et al. (2020) have determined that the congruence between technology and users' existing values, particularly in terms of perceived utility, shape their perspectives on the utilization and adoption of said technology. Parkes (2013) outlines how each individual has their own characteristics when considering using technology for a particular purpose. It is likely that for police officers, technology and its uses are standardised when solving crimes. These standards come into play in the process of resolving crimes, where each officer will try to adhere to the procedure but also have some individual preferences. This may require flexibility in the AR system to accommodate users to a certain extent. According to Bing et al. (2017), the effect of ITF on PU is not significant. Likewise, a study by Wu and Chen (2017) showed that ITF has almost no impact on PU; in this case, there was a lack of significance in determining PU levels. Thus, ITF is not enough to generate a PU sufficient to encourage technology acceptance. This may elucidate the reasons why there is little motivation in the PU of technology when it comes to the individual. Motivation is not linked to how a single user or individual considers it, but rather to functioning as a whole for multiple purposes. As this happens, there is a potential benefit in terms of the motivation to use the technology beyond the individual. This potentially makes it a communal affair, above all else.

H_3: ITF has a significant influence on PU of AR CSI training.

ITF and PEOU. Previous scholarly investigations, such as those conducted by Pal and Patra (2021) and Jung et al. (2020) have determined that the congruence between technology and users' existing values, specifically in terms of perceived ease of use, shapes their attitudes towards the utilization and adoption of said technology. Moreover, these research endeavours have illustrated that the fit between the task at hand and the technology influences both perceived ease of use. To elaborate, greater compatibility between the task and the technology increases the likelihood that users will consider the technology to be both easy to use and advantageous for accomplishing the task. The characteristics of the technology itself are pertinent to the efficacy of VR headsets. Bere (2018) mentioned that ease of use – the ability to easily use it for the intended purpose – has the potential to increase how many people may use technology. If the technology is not easy to use, it can potentially fail to make an impact and garner interest. As AR has many potential options, it may fit easily with the purpose of solving crimes according to the set standards and each person's unique method. According to Bing et al. (2017), the effect of ITF on PEOU is not significant. Likewise, Kurniawan et al. (2021) found that ITF has no impact on PEOU, which shows a lack of positive correlation and means that ITF has no real bearing on PEOU. Conclusions drawn from existing literature suggest that the perceived value in the study context, namely CSI training via AR devices, is contingent upon users identifying a harmonious relationship between the task and the technology. The predisposition of users to voluntarily engage with AR devices and their respective applications for training is likely shaped by the extent to which the task corresponds with the technology, thereby affecting their views on the ease of use of AR headsets and applications. This again shows the lack of impact that ITF or individual consideration has on technology; however, there may be a social element to the acceptance of technology, which is possible via social recognition or interest in adopting new technology.

H_4: ITF has a significant influence on PEOU of AR in CSI training.

3.14.3 PI

PI and PU. According to Park and Yoo (2020), usefulness is determined by how relevant the technology is to its intended purpose. The interactivity of AR is quite vast and significant; this can be daunting, yet it also creates a high potential for success. The idea is to have interactivity that caters to the individual so that they find AR useful in solving crimes. However, it is unclear from the literature whether PI has a major impact on PU. Essentially, interactivity can come in many forms, especially for AR/VR technology; its multiple manifestations can cause a lack of understanding about whether or not it is perceived to be useful. Other studies that employed AR and VR systems for CSI training have incorporated interactivity as a crucial component (Lukosch et al., 2012b, Solomon et al., 2019). This incorporation is necessitated by the requirements to elicit reactions from simulated crime settings, gather evidential material, and corroborate investigative findings (Makransky and Lilleholt, 2018). A study by Papakostas, et al. [62] posited that trainees found AR training systems easier to use when they perceived a high level of interactivity. Similarly, research by Papakostas et al. (2021) revealed that enhanced interactivity significantly improves a user's perception of the ease of using an AR system for trying on eyewear. Additionally, Huang and Liaw (2018) asserted that the perception of interactivity has a positive effect on the perceived utility of a virtual reality educational platform. Within the context of the present investigation, the experience of interactivity contributes to youthful researchers forming favourable opinions about the functionality and ease of use of the AR headset in CSI training contexts. Such perceptions consequently influence their behavioural inclinations toward training. By incorporating the interactivity of virtual tools and the surrounding environment as a foundational variable, the model is refined, and it leads to the generation of subsequent hypotheses.

H_5: PI has a significant influence on PU of AR CSI training.

PI and PEOU Lee and Lee (2019) highlighted how the interaction of a person with a technology can determine the extent of its potential use; in this case, if the interactivity is positive, it can lead to future uses and implementation of the technology. This interactivity is an especially important component of AR technologies, as typically a single user is engaged with one at a time. Shankar and Datta (2018) mentioned that PEOU has an impact on trust, which then impacts PI. Their study found a dependent relationship, with PEOU impacting PI but not the other way around. This highlights how trust is an important aspect of considering a new technology, especially when PEOU is responsible for setting it up. Trust is also a large social element that dictates how technology is seen or perceived; thus, it can highlight the potential for it to be seen as easy to use or considered valuable. With this, motivation can be potentially strong, and it becomes possible to ensure that the technology is used in the necessary settings. Overall, this is an important element to consider when trying to develop a strong PEOU to encourage the adoption of the technology.

H_6: PI has a significant influence on PEOU of AR CSI training.

3.14.4 IM

IM and PU. IM is one of the primary aspects involved in understanding how much a user uses technology, such as AR (Mayne & Green, 2020). When solving a crime, there is a level of IM that can potentially be met by trying to be in the scenario and ensuring that there are successful results. The literature does not clarify the impact of IM on PU. Kothgassner et al. (2012) emphasized that user acceptance increases with the level of immersion in a VR experience. The feeling of presence within the virtual settings—specifically crime scenes in this research—elicits intense emotional responses from participants. In a related study, Huang et al. (2016) identified a significant and favourable association between immersion and perceived utility; however, they did not find a noteworthy connection with the perception of usefulness. IM can be a complex aspect that makes it difficult to gauge any correlation or causation with PU. Thus, it is not apparent how IM may be of relevance here with PU, as per the literature.

H_7: IM has a significant influence on PU of AR CSI training.

IM and PEOU. According to Mayne and Green (2020), the ease of use of technology requires that it be able to overcome any barriers to entry into using it, such as the perception that it is hard. Essentially, any new technology, including the use of AR to solve crimes, requires some degree of learning and acceptance. Thus, there is the potential to ensure that the technology is used effectively. Khor (2014) found a strong positive correlation between IM and PEOU; in this case, IM had a direct and indirect positive correlation with PEOU, which indicates a strong link between the two, as IM helped to understand the new technology, which improved PEOU. Papakostas et al. (2021) posited that the level of interactivity perceived in an AR training framework has a favourable effect on the ease with which trainees can use the system. Similarly, research by Pantano et al. (2017) indicated that enhanced interactivity substantially improves a consumer's view regarding the simplicity of utilizing an AR system for trying on eyewear. Huang and Liaw (2018) also asserted that the perception of interactivity has a positive bearing on the perceived utility of a VR learning platform. With a strong level of IM, technology can be perceived as easy to use and relevant to the appropriate setting and needs. When this happens, it is possible to see the potential of IM in terms of determining its overall ease of use.

H_8: IM has a significant influence on PEOU of AR CSI training.

3.14.5 MOB

MOB and PU. According to Sanakulov and Karjaluoto (2015), mobile technologies are gaining significant traction and are becoming some of the most popular and regularly used platforms, including when users are outside. Solving crimes requires AR to have some level of MOB, as it can be complex with unique requirements. However, Lwoga and Lwoga (2017) found that MOB have a negative impact on PU: the higher the MOB, the lower the PU. Essentially, mobile technologies may have to compromise in some areas and might require more effort to use them properly. As seen in the literature, MOB is detrimental to PU, despite its potential use in solving crimes. This highlights how MOB should not be a main focus or consideration overall.

H_9: MOB has a significant influence on PU of AR CSI training.

MOB and PEOU. MOB is gaining more importance in technology, as it allows technology to be used whenever and wherever desired (Sanakulov & Karjaluoto, 2015). This can be a potential factor when trying to solve crimes using AR. For instance, if there is a need to go out and consider using AR for resolving crimes, then its MOB use can add to the perception of easy use. However, a study by Lwoga and Lwoga (2017) saw MOB having a negative impact not only on PU but also on PEOU. They highlighted that MOB is a negative consideration for PEOU because it can look daunting to users considering such a new technology. This further highlights the negative impact of MOB on both PU and PEOU. Another study argued that the perception of mobility plays a role in shaping the perceived ease of use concerning mobile devices, a notion that is applicable to AR devices as well (Park and del Pobil, 2013). As a result, MOB is severely limited in its ability to improve the acceptance of any new technology. MOB is seen as another hurdle to understanding and using any new technology effectively.

H_{10}: MOB has a significant influence on PEOU of AR CSI training.

3.14.6 IM

IM and PI. According to Albeedan et al. (2022), interactivity is one of the core components of an AR system, and the level of interactivity often determines how often and how much a system will be used by individuals. To help solve a crime, AR has to be able to accurately represent sorting through clues effectively, which might lead to more interaction in its use. Petersen et al. (2022) mentioned that IM impacts interactivity, which improves the chances of learning any new technology, including AR/VR. In a recent publication, it was discovered that the sense of immersion positively impacts the perception of interactivity when utilizing immersive display technologies. This proposition is applicable to this research in the context of adopting augmented reality devices (Salame et al., 2022). As a result, IM can improve perceptions of any technology's interactivity. As this happens, it can end up dictating how much technology is used overall, especially when it has high IM and fulfils the needs of the users.

H_{11}: IM has a significant influence on PI of AR CSI training.

3.14.7 MOB

MOB and IM. Rampolla and Kipper (2012) highlight how smartphones have gained significant traction due to the mobile nature of the technology, which allows users to use it as desired, such as while in transit for work. Similarly, MOB may be a key aspect of creating an IM level for police officers when developing AR technology for solving crimes. According to Jung et al. (2009), consumers have an expectation of IM with mobile technologies; however, it is unclear how much of an impact MOB has on IM. This again highlights the potential problems of MOB in terms of motivating people to adopt new technology; in some cases, MOB is detrimental, which makes its overall viability unclear. It is likely that MOB may also potentially cause IM problems. The constraint of visual obstruction in VR headsets has limited the examination of the interplay between movement and immersive experiences. In contrast, augmented reality gadgets permit users to move freely due to their transparent nature. Consequently, this research proposes that mobility is likely to be a key factor in the widespread adoption of augmented reality wearables, as their main advantage lies in providing immediate and straightforward access to data, leading to the ensuing hypothesis:

H_{12}: MOB has a significant influence on IM of AR CSI training.

3.14.8 PU

PU and BI. The intention of an individual highlights whether or not they will consider using a technology for a given purpose (Hess et al., 2014). The idea is to develop BI in police officers so that they will consider using AR to solve crimes. PU has a significant influence on BI, according to Abdullah et al. (2016), who found that PU was almost vital to determining BI among students with regard to e-portfolios. Thus, PU appears to play a vital role in determining BI. In this case, if a technology is seen as useful, then the intent to use it will be strong. This can highlight behaviour overall, and technology must be seen as pertinent to completing a task to be considered useful by the user. Numerous antecedent investigations have established that the perception of utility positively influences the acceptance of various technologies, such as wearable gadgets (Al-Emran et al., 2022, Guest et al., 2018) and mobile software (Shemesh and Barnoy, 2020, Rivera et al., 2015). Multiple academics have employed the TAM to assess behavioural intent for the adoption of VR headsets across different settings, finding a notable linkage between PU and BI (Tokel and İsler, 2015, Huang et al., 2016, Abd Majid and Mohd Shamsudin, 2019). In the specific setting of training, the impact of PU on the willingness to utilize VR headsets has been observed in sectors like higher educational training and adult e-learning (Vanduhe et al., 2020, Jimenez et al., 2020, Iqbal and Sidhu, 2022). In the realm of training for crime scene investigation with immersive headsets, a limited number of studies have applied TAM to explore the relationship between PU and BI (Solomon et al., 2019). However, no research has yet examined the role of AR devices in this particular context. Overall, BI is important to consider. According to Bing et al. (2017), PU has a significant impact on BI. Thus, in light of the preceding discourse, the current research proposes the subsequent hypothesis:

H_{13}: PU has a significant influence on BI of AR CSI training.

3.14.9 PEOU

PEOU and BI. Prayoga and Abraham (2016) highlighted that there must first be a general need and interest for a technology to be considered and used on a mass scale. This outlines the potential to develop intention through the ease of use of AR technology by police officers when trying to solve crimes. Verma and Sinha (2017) found that PEOU has a major impact on BI. Due to this, using this new technology must be made easy for users to accept it. Thus, ease of use has the potential to lower the barrier to using it, and this reduced barrier can then cause a technology to be considered more relevant to finishing the task, which causes the behaviour needed to consider it. The intention to use technology and the behaviour to use it are important aspects to consider. In a range of technologies, PEOU has been demonstrated to affect the inclination to embrace these innovations. King and He (2006) executed a quantitative examination of 88 studies, identifying a notable relationship between PEOU and BI across various technological contexts. Over the past twenty years, numerous investigations have employed the TAM to scrutinize the propensity of users to engage with VR, focusing on the ease of use parameter (Fetscherin and Lattemann, 2008, Bertrand and Bouchard, 2008, Chow et al., 2012, Tokel and İsler, 2015). Specifically for CSI training, one researcher carried out a VR experiment and ascertained a meaningful correlation between PEOU and the willingness to use VR headsets for the training exercises (Solomon et al., 2019). According to Bing et al. (2017), PEOU has an insignificant impact on BI. Notwithstanding the general consensus on this relationship between PEOU and BI in the adoption of VR technology, the field of augmented reality has received comparatively limited scrutiny, particularly within the scope of CSI training. Based on the preceding discourse, the current study proposes the ensuing hypothesis:

H_{14}: PEOU has a significant influence on BI of AR CSI training.

3.15 Conclusion

In this chapter, we comprehensively reviewed the aims, objectives, framework, and hypotheses of our study. To enable both qualitative and quantitative research, we opted for a mixed-method approach. We delved into the theoretical framework meticulously crafted for our crime scenario investigation. The proposed research framework illustrates the interconnectedness between key constructs: TTF, ITF, PI, IM, MOB, PU, PEOU, and BI.

Incorporating both qualitative and quantitative methodologies, we conducted interviews with senior investigators and gathered qualitative data from police academy experts. Subsequently, we formulated and presented fourteen hypotheses to address the research objectives effectively.

Moving forward, the next chapter will delve into a detailed discussion of the findings from our results, allowing us to accept or reject the hypotheses as appropriate. These results hold the potential to shed light on critical insights and contribute to a comprehensive understanding of the relationships among the identified constructs.

CHAPTER 4
SYSTEM DESIGN AND CAPTURING CRIME SCENE

4.1 Introduction

This chapter presents a comprehensive journey, encompassing the capture of the crime scene, its reconstruction in virtual mediums, and the development of a holographic application. This chapter is divided into two main parts, the first section provides an in-depth description of the crime scene capturing process, detailing the tools, techniques, and equipment utilised. It also highlights the challenges faced in obtaining photorealistic results that accurately replicate the real environment. Then, the second part demonstrates the philosophy of scene reconstruction that reflects on the system's design and the system components. It also comprises the technical process, features, functions, and challenges involved in getting a fully archival application that can deliver comprehensive practical training utilising this scanned scene. Generally, this chapter captures a glimpse of the crime scene to be a permanent digital archive with the privilege of interactions for younger investigators and trainees. This system can provide the ability to experience real crime scenes while overcoming all the limitations and obstacles that younger investigators and police officers normally face during actual crime investigations.

4.2 Part 1: Capturing Crime Scene

Capturing physical environments was quite cumbersome to get super realistic results that feature time details such as blood droplets and walls' inscriptions (Noghabaei et al., 2019). However, in the last few years, the data processing in 3D scanning and reconstruction techniques has evolved to serve the reconstruction of heritage sites (Milosz et al., 2020), particularly indoor cities (Pintore et al., 2020). The need for these applications accelerated the evolution of site reconstruction to be utilised for forensic purposes. There are some recent experiments that have adopted 3D scanning at crime scenes for reconstruction purposes and to map bloodstains and use them as evidence in court. However, they have successful results on exterior sites when compared with real references (Raneri, 2018, Ren et al., 2018). However, the attempts at capturing interior crime scenes were quite limited, as their aims were targeted at getting measurements of the clues and evidence from the scene, such as bullets, crime scenes, droplets, and blood traces (Amamra et al., 2019). Also, some projects used the reconstruction process to deploy into virtual reality experiences (Wang et al., 2019, Jani and Johnson, 2022, Mach et al., 2019). However, these experiments struggled to properly scan narrow rooms that have many blind spots for 3D scanners, which resulted in incomplete scenes in the immersive applications.

A series of 3D scanning and reconstruction techniques and pipelines have been reviewed and a series of consultations with experts in the reconstruction of cultural heritage sites have been conducted to get the finest results. A list of devices has been shortlisted to get the highest details for 3D point cloud laser scanners, such as FARO Scanner X130, Leica Scan Station P50 and RIEGL VZ-2000. The FARO scanner was chosen based on its availability and the scanning process is demonstrated in the next section.

4.2.1 3D scanning process (FARO Scanner)

Using the FARO scanner in interior venues is quite challenging for several reasons. The first reason is the proper lighting conditions and considering small rooms or venues have too many blind spots, it is hard to light them with balanced and distributed lights. The second reason is the need to capture many point clouds which means that the scanner has to be placed and perform a cycle of scanning multiple times in a single room. This is quite cumbersome in tight spaces, especially considering the rooms and the position of the scanner which may create self-blinded spots for the captured space. Moreover, blind spots such as under beds, sofas, lower shelves and cabinets are not captured when the scanner starts to perform laser scanning on top of the tripod at a height of one meter. Therefore, multiple scans have to be performed at different heights in different places in the same room. The third reason is that, due to capturing many scans in the same room, there should be a way to compose all of these scenes to enable the points cloud software to combine them into a single scene with all point clouds located in the exact location. Therefore, many ways have been explored to ease the process of connecting the scan results for each scan such as ball registers (Brazeal, 2013). These ball registers are a supplementary part of the scanner equipment, and they are usually placed in some positions so they can be processed and seen later in the 3D point cloud scene and to help the software combine multiple scans. These spheres were not efficient with small venues, particularly on the crime scene chosen for this experiment. Therefore, it is recommended to place another marker, provided by FARO - the manufacturer of the scanner - in the visible area of each scan. This marker should be positioned in a well-lit spot to ensure its proper capture in the scanned data. Then, in the composition stage, these patterns can be registered in all scans to connect all point clouds in one single scene. FARO scene was the software that was used to process the scanned data and to represent the point cloud to be edited and exported to another software.

Several experimentations were made using these checkerboard patterns and multiple laser scans in different venues with different light conditions to ensure the best possible pipeline that could be achieved for the actual crime scene – as depicted in Figure 4.1.

Figure 4.1: (left) ball registers from FARO, (Right) Checkerboard advised from FARO (FARO, 2021)

4.2.1.1 Preparing scene

Choosing the venue was not an easy procedure due to the complexity of finding an actual crime scene and all the relevant restrictions such as police approvals and privacy restrictions. Moreover, the most significant part is the importance of the clues in the scene that are needed for the forensic teams. The most applicable choice was using the educational crime scene facilities that are provided by the universities, such as 'Winchester University Crime Lab facility'.

The crime scene facility was on the top floor of a building comprised of two floors: a ground floor for forensic tools and the top floor dedicated to the crime scene. The top floor has two bedrooms in front of each other and a doorway in between. Therefore, for preparing the scene and considering multiple scans, defining the scanner's positions was a priority to ensure the cohesion of the final 3D scene that will combine all scan results.

The scene has been prepared in terms of the lighting condition as the main light was from daylight coming from the top and side windows, however, the scene needed extra lights as support sources to light dark spots. The scene also was prepared with representations of human victims. It has been adjusted by placing two mannequins to represent victims; one as a male victim sitting on a chair of a desk and the other as a female victim placed on the bed in the other room. Nine positions have been determined and against each scanner, a checkerboard pattern was stitched on the wall – as depicted in Figure 4.2. These patterns have been added to be captured in at least 3 scans and to be identified to perform the automatic registration by FARO Scene.

Figure 4.2: Crime scene Facility at Winchester University while FARO Scanner is working.

Nine scans were performed while the settings were adjusted on indoors mode, resolution ¼, scan size [Pt] 5120 x 2205, 11.3 million Points (MPts), and a quality of 4x. The scan has been captured with colours to generate panoramic textured images and to cover the point clouds generated. There are many attempts with different settings but the optimum settings were adopted from HERMAN (2020) as it produced good indoor results despite the guide being dedicated to external scenes – as depicted in Figure 4.3. Multiple scans have been captured at different heights to include spots under desks and chairs.

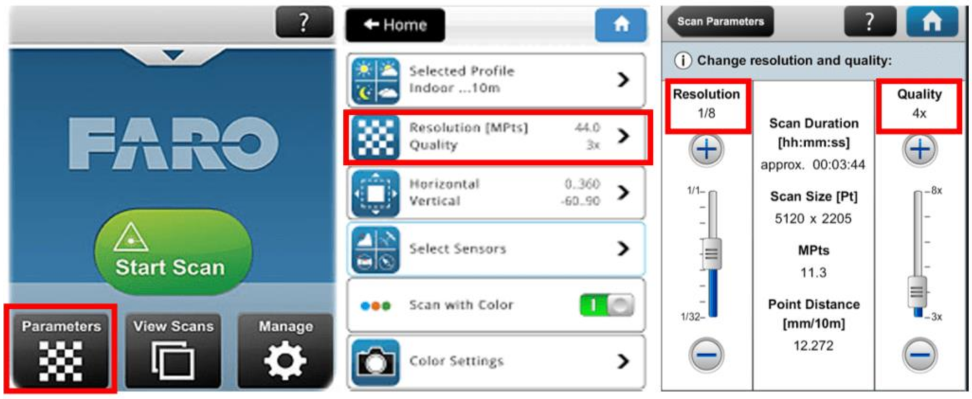

Figure 4.3: FARO 130x scan settings adopted from (HERMAN, 2020)

4.2.1.2 Cloud Points

After scanning, there are several stages involved, and these stages are managed using various software:

- **Scan Processing and Registration**: The first stage in post-processing involved using FARO SCENE to process the nine scans [Scan 00 – Scan 08], then some settings have been adjusted to conduct the automatic registration using the checkerboard patterns placed in the scene. The output as depicted in Figure 4.4, shows a complete 3D scanned scene represented in textures and combining all panoramic images generated from the scanner and the overlapped point cloud from all scans. The registration process has to find an overlap between each two scanned/cluster scenes. A total of 25 pairs of scans were matched and detailed information and analysis have been provided to justify the registrations.

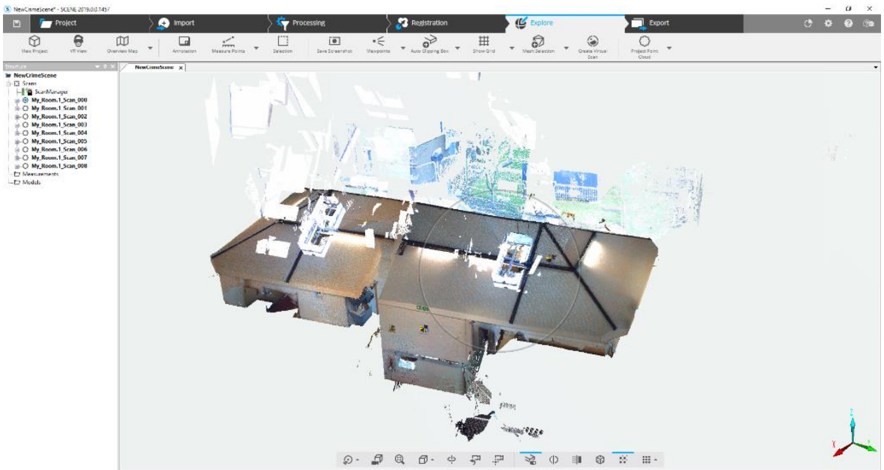

Figure 4.4: Generated scene combining all 9 scans for the crime scene facility.

As presented in Table 4.1, FARO SCENE produced the analysis of the combined scenes and for each pair of scans, there are some values such as:

- Mean [mm]: represents the tension between the corresponding scan points in each pair of scans.
- < 4 mm [%]: represents the percent of point with a tension less than 4 mm.
- Overlap [%]: represents percent of points clouds scanned that overlap.
- Used Points: Number of scanned points clouds used (FARO, 2022).

Table 4.1 Generated scene combining all 9 scans for the crime scene facility.

No	Cluster/ Scan 1	Cluster/ Scan 2	Mean [mm]	< 4 mm [%]	Overlap [%]	Used Points
1	Scan_06	Scan_00	0.967	88.6	39.2	6491
2	Scan_07	Scan_08	0.857	87.1	73.6	11497
3	Scan_07	Scan_06	0.804	87.9	81.0	12656
4	Scan_01	Scan_05	0.799	88.1	71.5	11969
5	Scan_06	Scan_05	0.783	90.1	56.0	9917
6	Scan_03	Scan_05	0.777	88.4	81.5	12831
7	Scan_02	Scan_05	0.772	87.6	83.0	9933
8	Scan_06	Scan_02	0.769	86.7	38.2	3660
9	Scan_01	Scan_00	0.755	88.8	87.0	13098
10	Scan_04	Scan_00	0.747	90.5	83.9	14583
11	Scan_08	Scan_05	0.746	88.5	67.5	8325
12	Scan_04	Scan_01	0.741	88.7	76.3	13948
13	Scan_02	Scan_00	0.735	88.0	87.9	11062
14	Scan_08	Scan_00	0.733	90.0	44.4	4887
15	Scan_03	Scan_00	0.733	88.9	83.7	13808
16	Scan_04	Scan_05	0.724	89.2	79.4	13162
17	Scan_02	Scan_03	0.722	88.0	85.1	12061
18	Scan_08	Scan_06	0.719	90.2	93.0	13391
19	Scan_07	Scan_05	0.717	87.8	57.5	7447
20	Scan_04	Scan_03	0.711	89.0	75.0	13912
21	Scan_02	Scan_01	0.693	89.1	88.5	12526
22	Scan_04	Scan_02	0.686	88.3	77.2	13977
23	Scan_05	Scan_00	0.659	89.7	79.6	18040
24	Scan_03	Scan_01	0.547	91.4	89.4	16148
25	Scan_07	Scan_00	0.544	89.0	32.3	3867
Overall Statistics			0.737	88.8		

The overall statistics showed that the overall mean for all tensions is 0.737. Additionally, the overall overlap below 4.0 mm is 88.8% indicating a successful registration according to the criteria set by the FARO guidance. A threshold of greater than 50% is considered an optimum result (FARO, 2022). At this stage, the model needs to be exported to be prepared for the cleaning stage.

- **Cleaning point clouds**: This stage involves using Autodesk Recap Pro to import and regenerate the scene for cleaning, which includes removing all irrelevant point cloud data inadvertently captured in the combined scene. As depicted in Figure 4.5, the scene has been cleaned as it is a required step to convert it to a 3D model and unnecessary points will distort the final model. Furthermore, an additional round of quality checks has been conducted within the same software to ensure accuracy.

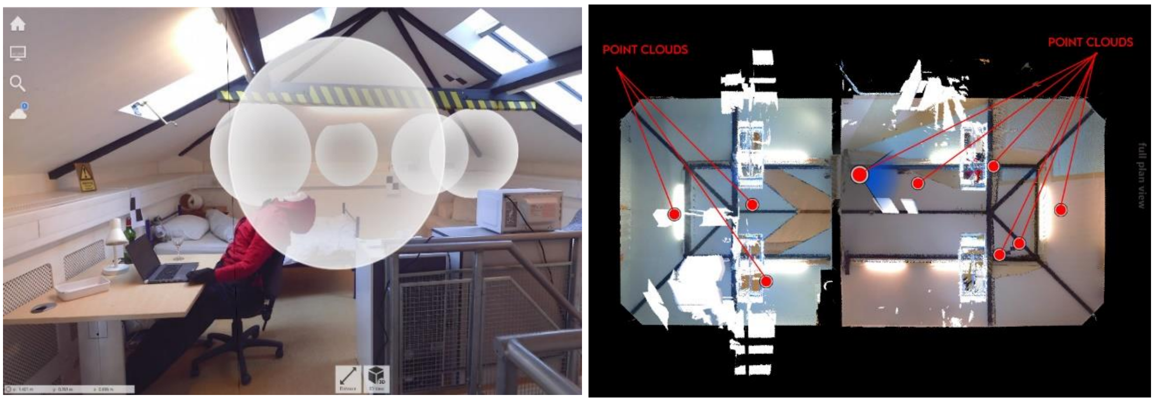

Figure 4.5: (Left) Spatial quality checks in Autodesk Recap Pro (Right) Cleaned scene in top-view

At this stage, Autodesk Recap Pro can export 3D models with textures. However, relying on the textures produced from FARO SCENE and Autodesk RECAP Pro would not be possible due to the poor quality produced as demonstrated in Figure 4.6.

The model exported from this stage was a raw model with a massive size, as it had 31 million polygons – 31,576,406 faces – which definitely this file size with this high number of faces can not be processed by any existing immersive headset (by the writing of this thesis) and their limited specifications. Therefore, the 3D scan process will pause at this stage till the photogrammetry phase is completed with its outputs.

Figure 4.6: 3D Scene from FARO SCENE showing the poor textures produced

4.2.2 Photogrammetry

The main reason for the photogrammetry phase in this pipeline is to generate textures from the entire scene to cover the 3D structure of the crime scene. The concept of photogrammetry depends on the relation between the points that construct the object space and the corresponding points of the image plane (Roos, 1951). Simply, it is about combining several images that have to be captured in a way with a significant overlap and some mathematical operations have to be done to generate a 3D model to map a certain space (Dostal and Yamafune, 2018). Several studies adopted new techniques for combining 3D scanning with photogrammetry techniques to get 3D structures from laser scanning and accurate textures from photogrammetry (Šašak et al., 2019, Alshawabkeh et al., 2021), particularly in the cultural heritage application due to the need for high texture details (Dostal and Yamafune, 2018, Liang et al., 2018). This new approach involved a thorough investigation of various techniques and software, as well as different methods of taking photos. The investigations encompassed all relevant factors, such as the optimum time of day, lighting conditions, camera types, camera settings, and flashes. Based on the best practices identified during these investigations, they were adopted for this experiment, which is further discussed in the next sections.

4.2.2.1 Camera settings

Canon EOS 5D Mark III with 22.3 megapixels full frame has been utilised and the setting was adjusted as follows; ISO 100, F/8, shutter speed 1/400. Given the high number of images required, the auto-focus option was chosen to expedite the process and obtain faster outputs.

4.2.2.2 Lens and flash settings

Due to the lack of good light distribution in the interior sites, an external flash is highly recommended to maintain the white balance and proper exposure in all captured images, therefore, the 580EX II was mounted on the Canon camera and its strength was adjusted to be between 1/16 and 1/8 depends on the lighting condition. The 18-55 is the standard lens for this camera and has been used for the photogrammetry experiment. Indeed 4 units of external lights have been fitted in dark areas to balance the lights while shooting. The way of capturing was quite systematic as it starts by defining the same positions of the laser scanner and placing the tripod that the camera is mounted on. The capturing process involved a complete 360-degree rotation. A shoot after shoot with a small angle between each capture to maintain at least 40 – 50% overlap. This would help the software to process a successful matching and stitching of all overlapped images more easily.

Figure 4.7: (Left) ‘Datacolor SpyderCheckr24’, (Right) Canon 5D camera with chosen settings.

Another tool that can make the post-processing easier is the ‘*Datacolor SpyderCheckr24’* which is a camera calibration card that can be placed somewhere in the room and has to be captured during the photogrammetry process. It will inform the post-processing software about how the colours were altered in this room, enabling it to create a tailored colour profile that can be applied to all captured images with ease using the Color Calibrator, as shown in Figure 4.7. The output of this stage results in 1457 images, taking from more than 11 positions of the camera, taking into consideration the blind spots and closer to the victims and the crime tool position. Indeed, not all images will be feasible for the process, and it is expected a number of images will be ignored due to the lack of overlap or significant differences between images under different lighting conditions. The next process is to import all of these images and proceed with the post-processing.

4.2.3 Post-Processing

At this stage, texturing is the main output needed as it will be combined with the laser scans that were produced earlier. Therefore, the photos captured have to be cleaned and adjusted before being imported into photogrammetry software, as discussed in the next sections discuss.

4.2.3.1 Colour Adjustments

Using Adobe Lightroom, we investigated the colour grading and filtering of the best images for the photogrammetry software. The process started by importing all images, especially the calibration card to create a tonality profile for the entire set of images. Then, tone and colour adjustments have to be done on the calibrator card before using these adjustments on all imported images. The next step was to check each image's white balance and tonality values and apparently, some of the images were taken quite fast without the sufficient level of lighting. Therefore, a total of 1291 have been considered to move to the next step, and 159 – about 10% - have been ignored, which is considered a good percentage of wasted images.

4.2.3.2 RealityCapture

RealityCapture is one of the most prominent software for photogrammetry, known for its capability to reconstruct textured 3D models. Therefore, it was initially adopted for this project. A total of 1291 images were imported from Adobe Lightroom and fed into the aligning process After processing, the software typically begins to create clusters of images based on similarities and overlaps it found between them. Each cluster of images contributes to constructing part of the 3D model. At this stage, users are required to identify specific points on each image, known as control points, to inform the software about similar images within each cluster. More than 40 control points created manually to link these clusters together, but all attempts were failed to connect all clusters to create one whole scene. The software was tested in exterior scenes and performed perfectly in finding similar images with the required overlap. As a result, the aligning process produced one cluster. However, it did not perform well with interior scenes, therefore, the experimentations shifted to another alternative software for conducting the photogrammetry.

4.2.3.3 Agi Soft Metashape

The reason for using this software is to capture complete 3D models including textures while taking care of the high-quality version of 3D construction which is already generated from the 3D laser scanning and its post-processing phase. Therefore, the model generated from Autodesk Recap Pro was imported as '.obj' to Metashape to reconstruct the scene again. This is in addition to all panoramic images taken by the laser camera and 1291 captured by the camera. After executing the alignment, the process outputted a reconstruction of the scene in a single 3D model with all textures on the model rendered. As expected, the model was still in a raw format, and it has 31 million faces and again it is not feasible for production yet. The results after processing were outstanding compared to the results produced from Autodesk Recap Pro earlier in the process – depicted in Figure 4.8. The results were even much better than internal rooms captured in other similar crime scene rooms that were recently published (Wang et al., 2019, Colard et al., 2013).

Figure 4.8: (Left) Laser scanning and photogrammetry results, (Right) Photo of the crime scene

4.2.3.4 Decimating Raw Models

This stage aimed to reduce the total size of the model to be feasibly used in headsets with limited hardware specifications, therefore the decimation started gradually from 31 million faces to 30 million, then reaching 100K faces for the final model. Based on experience, converting a high poly model to the lowest number of faces would distort the model and create more open holes. Therefore, the decremental approach is healthier for the model construction – as depicted in Figure 4.9.

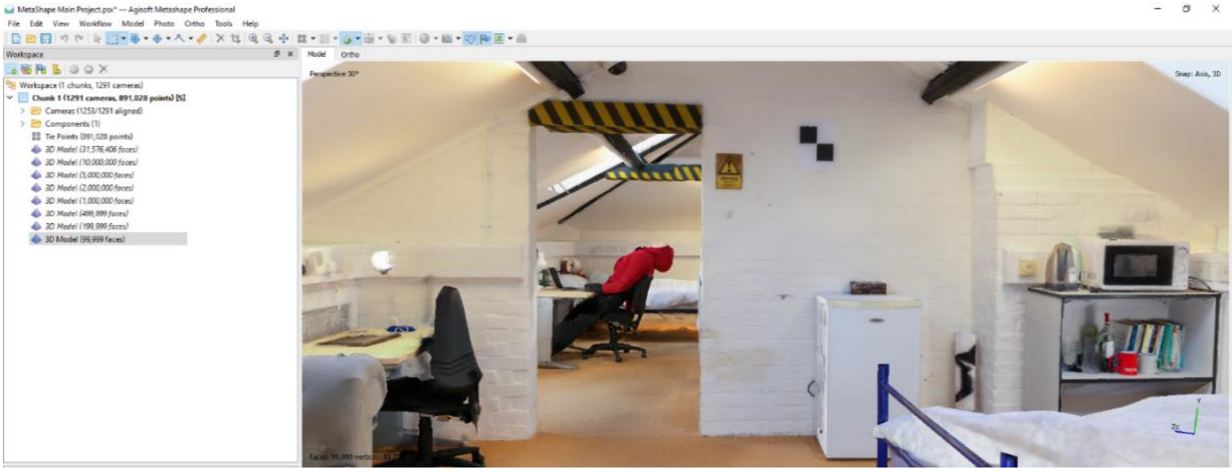

Figure 4.9: Decimation process in Agisoft Metashape

4.2.3.5 Texturing Crime Scene

Texturing of the crime scene was the final stage of preparing the scene to be used in the augmented reality system design. This stage involved using Adobe Substance Painter to paint some of the scene components to create some crime clues and mimic the real crime such as traces of blood, painting the crime tool, blood droplets, and fingerprints with and without blood on glossy surfaces as depicted in Figure 4.11. Adobe substance painters can export texture maps to be used later in the game engine used for augmented reality development.

Figure 4.11: (Left) Texturing crime scene with blood traces, (Right) painting the crime tool

4.3 Part 2: Augmented Reality Holographic System

The process of building a holographic augmented reality system for crime investigations training was quite challenging as these types of technologies have never been adopted in this domain. However, there are some technologies such as augmented and virtual reality which already have been yielded to serve police training in the last two decades (Eftekhari, 2011, Mayne and Green, 2020).

The system design is structured and implemented based on each step of the framework that is introduced in Chapter 3 - which was built on the framework introduced by (Beebe and Clark, 2005). Some other resources were reviewed to inspire the system design such as CSI4FS – the smartphone AR application for crime scene training (Levstein and Justice, 2019). Other similar training applications were very decent resources for constructing the training experience such as the virtual crime simulator produced by Conway et al. (2015). The researcher also input his own skills and experience of solving crimes with real cases into the structure of the system design. The process of designing the system went through many iterations according to the user-centred design approach to ensure the feasibility and the user experience needed.

4.3.1 System Design

The augmented reality system was built to utilise the capabilities of Microsoft HoloLens 2 and its ability to surround the user in mixed environments. The main aim is to superimpose the reconstructed crime scene which was previously scanned to conduct forensic investigation skills by junior police officers. Therefore, there are 4 different stages to enable the trainee to complete the investigation mission and to complete the case. The system was designed to move to each stage and spend time completing the task required in order to unlock the next stage. After the 4 stages end, the trainee will see a simulation of the entire crime and how the incident occurred, in addition to the way the criminal altered the scene. As depicted in Figure 4.12, the system design is presented based on the user's workflow since the application starts passing by all stages and ends by being at the main scene again. The following sections will explain in detail what each stage includes.

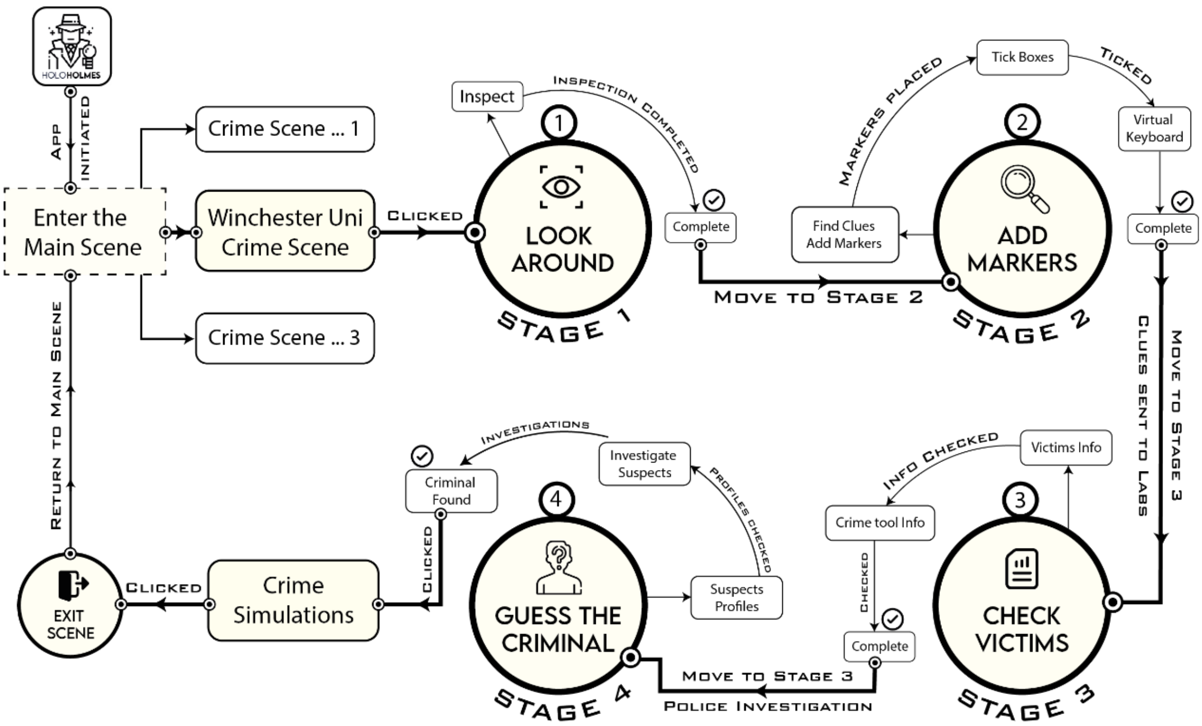

Figure 4.12: The AR Crime Scene Investigation- HoloHolmes- system design

4.3.1.1 Development Cycle

It was critical to define the development tools that will be used for the augmented reality application. Since Microsoft HoloLens was released, Microsoft developed toolkits to encapsulate all the functions that the headset can provide in the most usable manner. Therefore, MRTK was released to be supported by Unity game engine. Unreal Engine was one of the alternatives; however, support was provided to Unity developers and Microsoft HoloLens forums assured the choice for adoption at this phase. Therefore, Unity and the scripting language C# were used in combination with MRTK for HoloLens to build the HoloHolmes. After building the application, Microsoft Visual Studio has been used to deploy the application files to the headset while being connected to it.

4.3.1.2 Getting Models into Virtual Scene

The first phase of the development was to migrate the scene and its components that are exported from the 3D software. This also includes all texture images required to display the scene, which was exported from Adobe Substance Painter with meshes. Defining the shader that can display the real textures of the scene was a complicated stage as HoloLens is not able to display all of the realistic colours and tone values. Therefore, testing standard shaders showed drawbacks in showing textures and the shades faded with the actual colours. Several attempts occurred to test the most appropriate shader, including the ‘Mixed Reality Toolkit’ shader as it resulted in a semi-transparent environment. The most appropriate shader was ‘Unlit/Texture’; despite the lack of shadows in the scene, it was the best representation of the scene after being projected on the lens. As seen in Figure 4.13, the scene has been displayed in a more credible way showing all the features required. In the main scene, the user has to choose between different crime scenes by simply touching the desired scene to move to it. As displayed, there are three different scenes available for interaction.

Placing the 3D model of the room was not a straightforward step, as the scaling of the room had to match the real crime scene. Therefore, many attempts have been undertaken to match the size of the room, and also the alignment of the virtual ground had to be aligned with the real ground; otherwise, the user would be unbalanced and confused.

After deploying the initial version of the application, the testing had to take place in a very wide space, and it is preferred to be much wider than the crime scene space. This is due to having the physical environment interfere with the virtual crime scene caused confusion to the user. It is also preferred that the location of displaying visuals be chosen without any physical obstacles existing to allow users to be immersed in the virtual scene without being obstructed by any barriers. Moreover, having more obstacles in the physical environment would affect the health and safety of the user due to switching the entire focus to the virtual rather than the physical world.

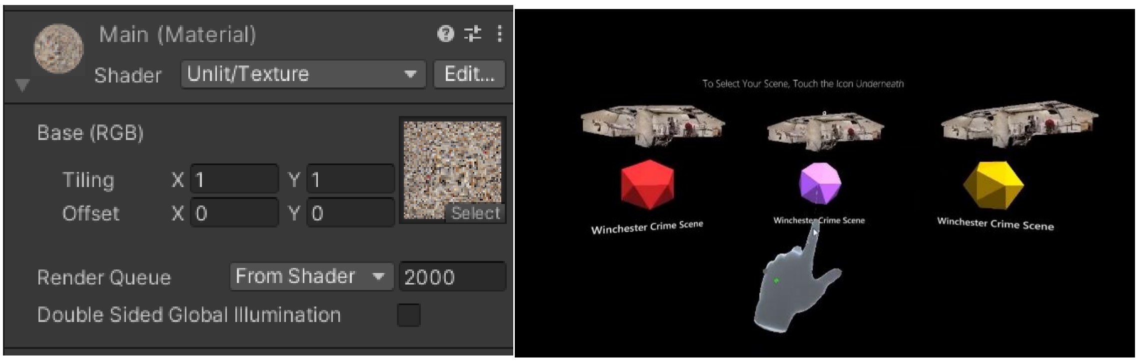

Figure 4.13: (Left) Unity shader used for the 3D scanned scene, (Right) how the 3D scene is displayed

4.3.1.3 User Interface using MRTK 2.0

MRTK is a Unity plugin or tool for developers that provides certain components and features to accelerate augmented reality applications that can be developed in the Unity game engine (Semple et al., 2022). This toolkit makes the process of creating the user interfaces much easier, as it provides input systems in a cross-platform manner along with necessary blocks for spatial interactions and User Interfaces (UI). It also boosts the ability to create prototypes in the Unity editor simulation allowing developers to see changes simultaneously instead of waiting to deploy the application and display it via the HoloLens.

The toolkit was highly beneficial for designing the user interfaces for each informative station and stage. MRTK provides windows that include buttons to make it disappear or to activate scaling its size. Additionally, it has buttons to make it follow the user wherever he/she goes. Touching and interacting mechanisms and pinching objects have evolved since the release of Microsoft HoloLens 2 in 2019, as it was cumbersome to perform a specific hand gesture simultaneously while pointing to objects with the user's head. Now, interactions have become much easier, particularly after the HoloLens camera's artificial intelligence can understand neutral hand gestures. Furthermore, the MRTK facilitates touching and holding objects from both near the object and at a distance. As demonstrated in Figure 4.14, if the user is near the object, he/she can easily hold it naturally with a reality-mimicking sound effect and the object can respond to the user. Additionally, if the user is far away from the object, he/she can point to it with a visible dashed line to show the ability to control it from a distance and again, the object can respond too. The only condition for responding to be controlled is to set the object as a 3D rigid body in Unity.

The MRTK yielded the virtual objects to be flexible, movable, and scalable through visible boundaries, and the user can easily aim by using their hands to scale objects and move them anywhere in the mixed worlds.

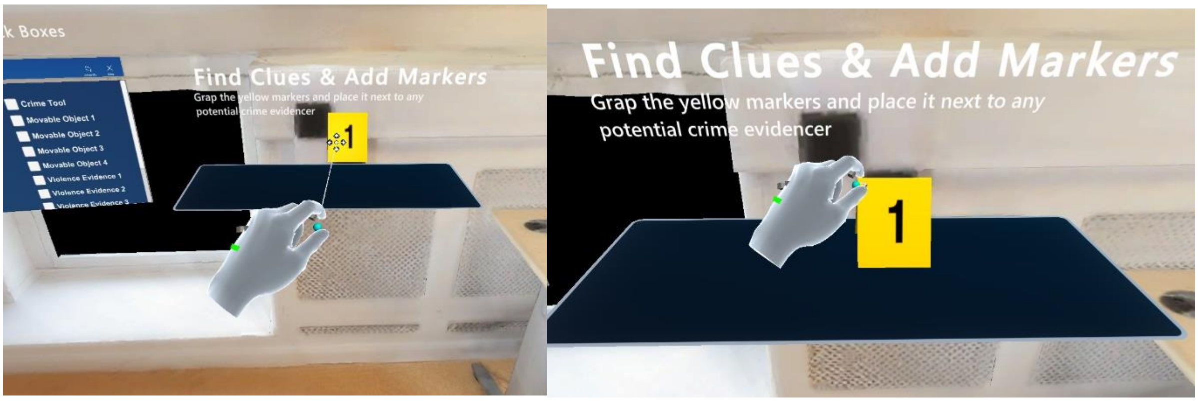

Figure 4.14: (Left) holding objects from a distance, (Right) pinching the object

4.3.1.4 Stage 1: Look around

At this stage, the user will start to be familiar with the reconstructed environment and his/her position in it. The objectives of this stage are to generate a generic impression about the way the crime occurred and possibly answer some questions. These questions could be; How did the criminal enter the crime scene? How were the victims murdered? Does the crime tool still exist? What was the motivation for the crime? Then, are there any visible blood traces? etc.

The application was designed to position the user exactly in front of the investigation control to acknowledge that this is the reference point of the scene. Therefore, users will have to explore the investigation control area and understand that whenever they get disoriented in the scene or want to change anything, they have to return to this spot to make the change. The investigation control station is designed to be 4 sequential stages and according to the principles of user experience, this informs the user of a clear and certain scenario the user has to follow in order to accomplish the task. The visibility of the icons of the completed tasks and the future locked tasks also contributes to the continuity of the journey of solving the case, enhancing this particular user experience.

Hence, the user will have to press the button with either a single or multiple fingers in the first stage button, then a new floating window interface – with the title "Look Around" shows with instructions while an audio narrator is reading the apparent instructions text – as depicted in Figure 5.15. The user has to do the investigation and walk around and once the tour is done, the user has to go back to the investigation control and press a small button beneath 'Stage 1' named 'Complete'. Once pressing it, the appearance of the Stage 2 button changes from a transparent button to a real pressable button.

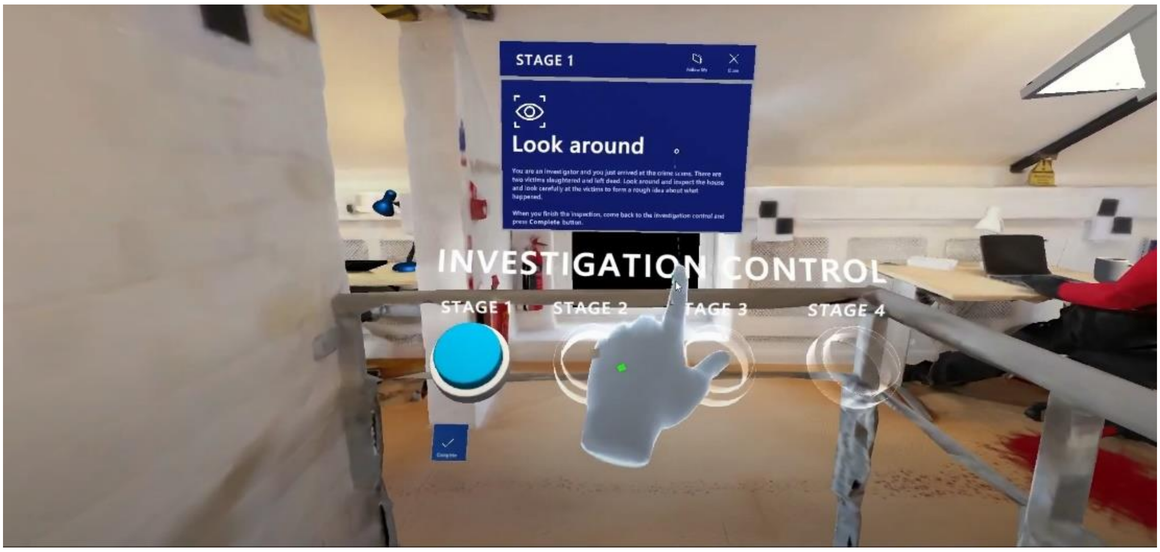

Figure 4.15: Stage 1 “Look around”

4.3.1.5 Stage 2: Find Clues

This stage focuses on the most prominent investigation skill, which is finding clues about the crime. Therefore, the task for this stage was designed to practice finding evidence and clues in the example scene. The main aim of this stage is to practice the ‘Finding clues’ task by investigating the crime scene after reporting the incident. The proper practice is to have a very critical and exploratory eye to see the changes in the scene and to recognise moved objects or any damage in the environment e.g., walls, objects, grounds etc. Once the user presses the button of stage 2, a new floating window shows with an audio narrator again with the instructions. A floating board awaits the user with a stack of crime scene tags near the front wall. This board has been titled with a big text 3D mesh with descriptions for the user on how to use these tags.

The augmented reality application designer considers the lack of user experience on these certain applications, so relying on text for instructions was not enough. Therefore, some animated guides were designed to display how to hold virtual objects – the tags - and move with them to the targeted spots – as depicted in Figure 4.16. A scaling feature has been added to the virtual tags in case of placing them in an unclear spot.

Figure 4.16: Animated guides for placing tags

The tags board has a mechanism to generate new tags with the following numbers once the user holds a previous tag. Therefore, the user has to pinch the tag to hold it and move to the suspected clue's spot and drop it on top of the surface. 24 tags are available to be placed in the two connected rooms. There is a blue textual board floating next to the tags board which presents 24 checkbox statements. This informative board categorise the tags based on each type, so the investigator has to limit the number of tags based on their types and that makes the quiz much easier to count them. The categories have been divided as follows; 3 Blood evidence, 9 Fingerprints, 1 Crime tool, 4 Moved objects and 6 Evidence of Violence. Once the user puts the tag on their spots, the board can allow the user to tick the box to make the counting process much easier. It is expected that the user place all of the 24 tags as advised in the informative board. Figure 4.17 shows how the tags have been placed in all of the suspected clues in the example scene.

A virtual keyboard is an additional function which was added to this stage for any additional notes that the investigator might want to take regarding the crime. Once the user presses the floating button 'Keyboard', a virtual keyboard will be visible and the user can type all notes. The notes will be left floating next to the informative board.

Figure 4.17: Stage 2 "Find Clues"

Completing this stage is conditional to placing all of the 24 tags as well as ticking all boxes in the checklist on the informative board. If the user returns to the investigation control spot without completing the task, the complete button beneath stage 2 will be invisible. This will give an indication to the user that the task has not been done yet.

4.3.1.6 Stage 3: Check Victims

This stage starts by informing the user that did a decent job regarding the collection of evidence and clues to be examined at the forensic labs if they did so. Therefore, the biometric information regarding the victims and any potential evidence regarding the potential criminal has been analysed and identified between stages 2 and 3. The communicative board will start to ask the user to go around and check the new visible buttons next to the victims and the crime tool to reveal the information that has been released from the forensic lab. This stage is considered an interactive formative task which mimics the real-cases scenarios of investigation. It is essential to follow the process of communication between the investigators and the forensic team and ensure the data is exchanged back and forth.

Therefore, the investigator at this stage will be asked to reveal the identities of the victims by pressing some floating buttons to reveal another informative floating board with audio narratives – as depicted in Figure 4.18. The information revealed mimics how the reports are represented in real cases. These boards have buttons to follow the user if pressed and if the user moves to keep the information displayed simultaneously with being narrated. Also, there is a button for the crime tool -Knife- with information displayed and narrated acoustically detailing how it was used to murder the victims.

Completing this stage is conditional on revealing all updated forensic information to make the user acknowledge more about the crime under investigation. The condition of the stage completion has been programmed by pressing all new buttons revealed in the scene to display them. Once all buttons are pressed, the user can return and see the complete button is revealed to end this stage.

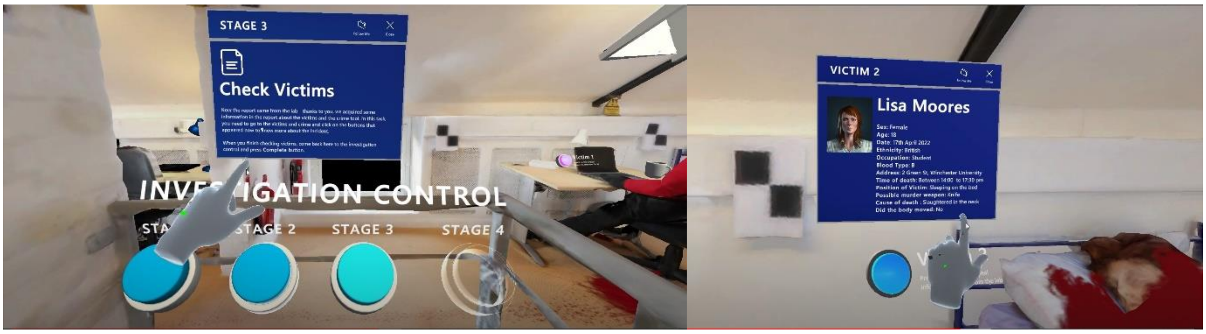

Figure 4.18: Stage 3 "Check Victims"

4.3.1.7 Stage 4: Define the Criminal

This stage emphasises another skill of the investigation process, which is identifying the criminal from multiple subjects while the collected evidence fails to do the job. This stage aims to continue the investigation process and solve the case by moving and revealing the information regarding all suspects of the crime. Suspects have been recognised based on the biometric evidence found at the scene and the information provided by friends or relatives of the victims and the police records.

The task begins by pushing the button of stage 4, and then the informative formative board will be displayed simultaneously with the acoustic instructions to tell the user to go to the front wall to initiate the investigation tool named "Guess Who Is the Criminal!" – as demonstrated in Figure 4.19. Next, the user will approach the wall to see a button to press with some classified profiles that are ready to uncover personal information regarding the crime suspects. The investigator will start to press a button to reveal the information of each profile while the acoustic narrator is playing simultaneously. The profile shows information such as name, relationship with the victims, whether he/she was seen on the day of the accident or not, whether he/she had a key to enter the property or not, and whether his/her biometrics e.g. blood or fingerprints, were found at the scene or not.

To optimize user experience, the application prompts users to review all profiles. A designated button, 'Further Investigation,' allows users to delve deeper into a suspect's case, involving CCTV scrutiny or requesting more data. Multiple purposeful buttons exist here due to the complexity of investigator tasks. Each button has unique visuals and audio responses for AR app clarity. Pressing 'Further Investigation' reveals a new interface with results confirming suspect involvement. A prominent 'X' streamlines choices after an investigation by removing incorrect suspect details. Typically, one choice identifies the criminal, verified through continued investigation. A new signpost guides users to the investigation control panel with an additional button for further actions.

Figure 4.19: Stage 4 “Define the Criminal”

4.3.1.8 Simulation

Normally, after recognising the criminal and detaining the victim, simulating the crime can recall what really happened at the crime scene and connect all evidence with the conducted actions (Christianson and Bylin, 1999). It also adds a sense of validity to what was claimed at the investigation with the criminal and the evidence found at the scene (Carmel et al., 2003). This part was significant as it connected all pieces of the puzzle together; therefore, it was essential to display an animation of the entire crime.

Hence, the user will return to the investigation control spot to find a distinctive button designed for animation and signposted as the simulation. Once pushing the button, a 3D character representing the criminal will appear in the virtual environment and walk around with the crime tool. The 3D character that resembles the criminal was designed to replicate the human life-size, thereby enhancing the credibility of the simulation process, as illustrated in Figure 5.20. The investigator at this moment can watch and connect every single action with the evidence found earlier. The animation will run once, and the button will possess the capability to replay it if pressed again. This feature allows users to review the simulation as needed for a more thorough understanding of the crime scene recreation. The avatar will perform actions like walking around, committing murder, robbing the house, and creating a mess. Finally, it will leave the crime scene at the spot where the reported crime tool was found. The animation allows investigators to understand the sequence of events and their connection to the evidence. At this stage, the investigator will get a rewarded floating board with the statement “You Solved the Case!”. Then, a new button will display to return to the home scene which has multiple cases and missions that need to be solved.

Figure 4.20: Crime simulated with an animated avatar as a 3D Character.

4.3.2 Technical limitations

Augmented reality applications are still in the developmental stages concerning both hardware and software, resulting in existing limitations such as a limited field of view (FOV) (Trepkowski et al., 2019). This narrow FOV conceals a wider portion of the virtual environment and related user interface objects, potentially confusing users. To address this, specific techniques have been incorporated into the application design, ensuring continuous visualisation of UI elements during navigation in mixed worlds. Furthermore, to display a high-quality 3D model of the scanned crime scene, a more advanced headset is required. However, to overcome hardware constraints, a lighter version of the model is utilised after compression and polygon reduction. Unfortunately, this compromises the fine details crucial for a thorough investigation.

4.4 Conclusion

This chapter showcases the augmented reality system design, 'HoloHolmes' and its constituent components. It provides a comprehensive explanation of the construction process, catering to academics, researchers, and developers interested in building crime investigation systems using augmented reality. The system demonstrated here serves as a valuable training tool for young investigators and police officers. Additionally, it facilitates archiving real crime scenes by scanning and presenting them to investigators, police officers, and forensic teams. The system also provides a shared interactive experience enabling multiple members of the investigation team to coexist within the same scene and collaboratively explore the scene.

CHAPTER 5
RESULTS, DISCUSSION AND EVALUATION

5.1 Introduction

As outlined in the methodology chapter, the primary objective of this study was to train young police officers in crime investigations through the development of a systematic augmented reality AR application, leveraging Microsoft HoloLens 2 to elevate searching evidence, and conducting professional methods of investigation. The ultimate aim was to achieve more efficient and accurate investigative practices for crime scenes. This chapter is dedicated to detailing the quantitative and qualitative methods employed to gather findings, which were gathered through questionnaires and interviews. Additionally, the techniques used to address the study objectives are thoroughly examined and discussed. To achieve these aims, the following objectives need to be addressed:

- To evaluate the augmented reality application that was designed and deployed on an AR headset (Microsoft HoloLens 2) to train police officers in crime scene investigation, particularly after the evidence was collected, to achieve the highest efficiency possible.
- To evaluate the AR system through qualitative and quantitative data collection from police academy experts and students/participants to validate and evaluate the usability and usefulness of the system using the technology acceptance model integrated with the task-technology fit model.

5.2 Demographic Profile

The qualitative data were collected from police academy experts, while the quantitative data were collected from police academy students. Table 5.1 shows the demographic information of the experts. The results indicated that most of the male police academy experts were in the age group of 40–60 years old. When asked about their education level, the majority of experts had a BSc degree, and the rest those with an MSc degree. In terms of their job titles, most of the experts were senior crime scene officers or crime scene officers with several years of experience. Interestingly, most of the experts had experience in AR/VR.

Table 5.1 Experts' Demographic Information

Job	*Gender*	*Age*	*Degree*	*Years of Experience*	*Experience in AR/VR Apps*
Senior Crime Scene Officer	Male	38	BSc	15	Yes
Crime Scene Officer	Male	40	MSc	18	Yes
Crime Scene Officer	Male	45	BSc	20	Yes
General Manager of the Evidence Department	Male	60	BSc	35	No
Head of Crime Scene Department	Male	48	PhD	15	Yes
DNA Crime Scene Officer	Female	40	MSc	15	Yes
Director of the Crime Scene Department	Male	50	BSc	25	No
Crime Scene Officer	Male	52	BSc	27	No
Deputy Manager of the Evidence Department	Male	55	BSc	30	No
Crime Scene Officer	Male	46	BSc	26	Yes
Senior Crime Scene Officer	Male	65	MSc	37	Yes

Table 5.2 Participant's Demographic Information

Variables Measures		***N***	**%**
Gender	Male	118	73.7
	Female	42	26.2
Age	18–25	0	0.00
	26–34	80	50.0
	35–45	76	47.5
	46–60	4	2.50
Level of Study	A-LEVEL	27	16.8
	Bachelor	86	53.7
	Masters	37	23.1
	PHD	10	6.25
Which of the following VR devices have you heard about (before the experiment)?	Oculus Quest (1 or 2)	12	7.50
	Samsung VR	36	22.5
	HTC Vive	11	6.87
	HoloLens	41	25.6
	I have not tried any of the above devices	60	37.5
Have you ever used either an AR or a VR headset?	Yes	92	57.5
	No	68	42.5
If this system can improve your investigative skills, will it increase your intention to use it?	Yes	160	100
	No	0	0.00

5.3 Quantitative Analysis

In this study, police academy students were involved who practised crime scene investigation as part of their studies. The questionnaire consisted of eight constructs, including TTF (task technology fit), ITF (individual technology fit), immersion (IM), PI (perceived interactivity), MOB (mobility), PEOU (perceived ease of use), PU (perceived usefulness) and BI (behavioural intention). The questionnaire used a five-point Likert scale ranging from 1=strongly disagree to 5=strongly agree. The questionnaire was completed by 160 students.

5.3.1 Analysis Method

The data was collected and analysed using IBM SPSS software. To validate the system's utility through TAM that is integrated with the task technology fit framework, the study employed a Partial Least Squares Structural Equation Modelling (PLS-SEM) methodology via SmartPLS 4.0. The hypotheses' validity was also examined using SmartPLS 4.0. This study utilised a two-stage statistical approach, as advocated by Hair et al. (2012). The initial phase encompassed the assessment of measure validity, which comprised both convergent and discriminant validity. The secondary phase was dedicated to including the examination of the structural model. Defining the sample size was reliant on an equation formulated by Krejcie and Morgan (1970), based on the population size. For the computation of the sample size, as indicated in the following equation, the probability value was set at p = 0.05, implicating a chance of committing a type I error, or p < 0.05.

$$s = \frac{X^2NP\,(1-P)}{d^2(1-N)+X^2P\,(1-P)}$$

Here, (S) refers to the necessary sample size, (N) defines the overall population size, (P) represents the population proportion (presumed to be 0.50 to yield the maximum sample size), (d) denotes the level of accuracy as a proportion (0.05), and (X^2) is the chi-square table value for 1 degree of freedom at the desired confidence level (0.05 equating to 3.841).

5.3.2 Results

In assessing a measurement model, the implementation of the Confirmatory Factor Analysis (CFA) led to the exclusion of two items, retaining only those with factor loadings exceeding 0.05. As a result, the final analytical framework consisted of 29 items, which served as the basis for the subsequent confirmatory reflective analysis. Table 5.3 illustrates the results concerning internal consistency reliability and convergent validity.

Both the TAM and the TTF framework for CSI training were affected by additional variables related to the behavioural intention to utilize AR devices and applications. In terms of evaluating the proposed model's reliability, Cronbach's alpha coefficients ranged between 0.731 and 0.851, exceeding the benchmark of 0.7 set forth by Nunnally (1994). The concept of validity is crucial and warrants rigorous assessment. Accordingly, Table 5.3 reveals that the Composite Reliability (CR) indices ranged from 0.713 to 0.899, exceeding the minimum recommended value of 0.70 as cited by Ab Hamid et al. (2017) and Mitrany (1945). This confirms the reliability of all variables under consideration.

Table 5.3 Convergent Validity Results

Construct	Items	Factor loadings	Cronbach's Alpha	CR	AVE
BI	BI1	0.794	0.826	0.882	0.653
	BI2	0.741			
	BI4	0.818			
	BI5	0.873			
IM	IM1	0.786	0.738	0.817	0.691
	IM2	0.874			
	IM3	0.789			
ITF	ITF1	0.833	0.741	0.809	0.586
	ITF2	0.729			
	ITF3	0.730			
MOB	MOB1	0.864	0.790	0.831	0.711
	MOB2	0.825			
	MOB3	0.822			
PEOU	PEOU1	0.823	0.851	0.894	0.629
	PEOU2	0.768			
	PEOU3	0.816			
	PEOU4	0.816			
	PEOU5	0.738			
PI	PI1	0.751	0.731	0.813	0.686
	PI2	0.899			
	PI3	0.835			
PU	PU1	0.821	0.805	0.870	0.627
	PU3	0.811			
	PU4	0.793			
	PU5	0.739			
TTF	TTF1	0.734	0.789	0.863	0.613
	TTF2	0.852			
	TTF3	0.824			
	TTF4	0.713			

Validity was scrutinized through both convergent and discriminant validity measures by Hair Jr et al. (2021). Convergent validity was assessed by calculating the Average Variance Extracted (AVE) along with factor loadings (Hair Jr et al., 2017). As shown in Table 5.3, all constructs had values ranging from 0.586 to 0.711, surpassing the minimum threshold of 0.50 as specified by Hair Jr et al. (23). Since all factor loadings for the constructs exceeded the cut-off value of 0.70, it was concluded that the model possesses adequate convergent validity.

The discriminant validity is evaluated by inspecting the Fornell–Larker criterion and cross-loadings (Hair et al., 2014). As can be seen in Table 5.4, as per the Fornell–Larker criterion, the diagonal values (square root of AVE) are higher than the off-diagonal values of all rows and columns (Fornell & Larcker, 1981). These values showed a positive correlation coefficient between the constructs.

Table 5.4 Fornell–Larker Criterion

	BI	IM	ITF	MOB	PEOU	PI	PU	TTF
BI	**0.808**							
IM	0.511	**0.831**						
ITF	0.601	0.528	**0.765**					
MOB	0.446	0.413	0.551	**0.843**				
PEOU	0.683	0.461	0.656	0.536	**0.793**			
PI	0.561	0.513	0.577	0.574	0.605	**0.828**		
PU	0.594	0.508	0.53	0.517	0.651	0.455	**0.792**	
TTF	0.613	0.469	0.762	0.385	0.552	0.487	0.545	**0.783**

Cross-loading results can be seen in Table 5.5. The item loadings related to each construct were greater than the content of its corresponding variables. Thus, it can be recommended that there be no doubts about the assessment of discriminant validity in this study.

Table 5.5 Cross Loadings

	BI	IM	ITF	MOB	PEOU	PI	PU	TTF
BI1	**0.794**	0.440	0.549	0.411	0.498	0.389	0.496	0.493
BI2	**0.741**	0.364	0.448	0.373	0.426	0.373	0.384	0.457
BI4	**0.818**	0.409	0.51	0.304	0.66	0.496	0.572	0.560
BI5	**0.873**	0.437	0.433	0.376	0.578	0.531	0.437	0.459
IM1	0.323	**0.786**	0.411	0.273	0.359	0.310	0.427	0.420
IM2	0.509	**0.874**	0.464	0.402	0.405	0.521	0.421	0.369
IM3	0.521	**0.789**	0.398	0.462	0.543	0.455	0.387	0.414
ITF1	0.542	0.456	**0.833**	0.487	0.543	0.446	0.418	0.621
ITF2	0.401	0.473	**0.729**	0.465	0.467	0.538	0.429	0.477
ITF3	0.430	0.277	**0.730**	0.307	0.495	0.339	0.370	0.651
MOB1	0.369	0.327	0.471	**0.864**	0.481	0.562	0.494	0.414
MOB2	0.420	0.411	0.423	**0.825**	0.593	0.429	0.382	0.477
MOB3	0.386	0.374	0.459	**0.822**	0.420	0.396	0.372	0.224
PEOU1	0.561	0.370	0.478	0.473	**0.823**	0.538	0.460	0.389
PEOU2	0.555	0.409	0.585	0.376	**0.768**	0.449	0.513	0.460
PEOU3	0.565	0.324	0.577	0.416	**0.816**	0.469	0.563	0.515
PEOU4	0.544	0.352	0.537	0.534	**0.816**	0.495	0.509	0.424
PEOU5	0.473	0.376	0.410	0.309	**0.738**	0.445	0.543	0.393
PI1	0.374	0.309	0.539	0.415	0.435	**0.751**	0.255	0.434
PI2	0.536	0.512	0.449	0.527	0.556	**0.899**	0.466	0.393
PI3	0.574	0.366	0.431	0.432	0.502	**0.835**	0.412	0.366
PU1	0.482	0.305	0.447	0.395	0.558	0.411	**0.821**	0.484
PU3	0.480	0.378	0.394	0.356	0.536	0.440	**0.811**	0.460
PU4	0.489	0.498	0.452	0.478	0.534	0.379	**0.793**	0.395
PU5	0.425	0.422	0.382	0.405	0.429	0.201	**0.739**	0.387
TTF1	0.430	0.315	0.561	0.224	0.406	0.362	0.405	**0.734**
TTF2	0.544	0.437	0.624	0.294	0.429	0.307	0.425	**0.852**
TTF3	0.509	0.374	0.611	0.420	0.543	0.537	0.478	**0.824**
TTF4	0.429	0.340	0.596	0.236	0.314	0.278	0.390	**0.713**

5.3.2.1 Hypothesis testing

In the structure model evaluation, the hypothesis testing was performed through a bootstrapping method of 3,000 re-samples by measuring the std.beta (β), *t*-values and p-values. Before testing the hypothesis, an algorithm for the research model was created (Figure 5.1).

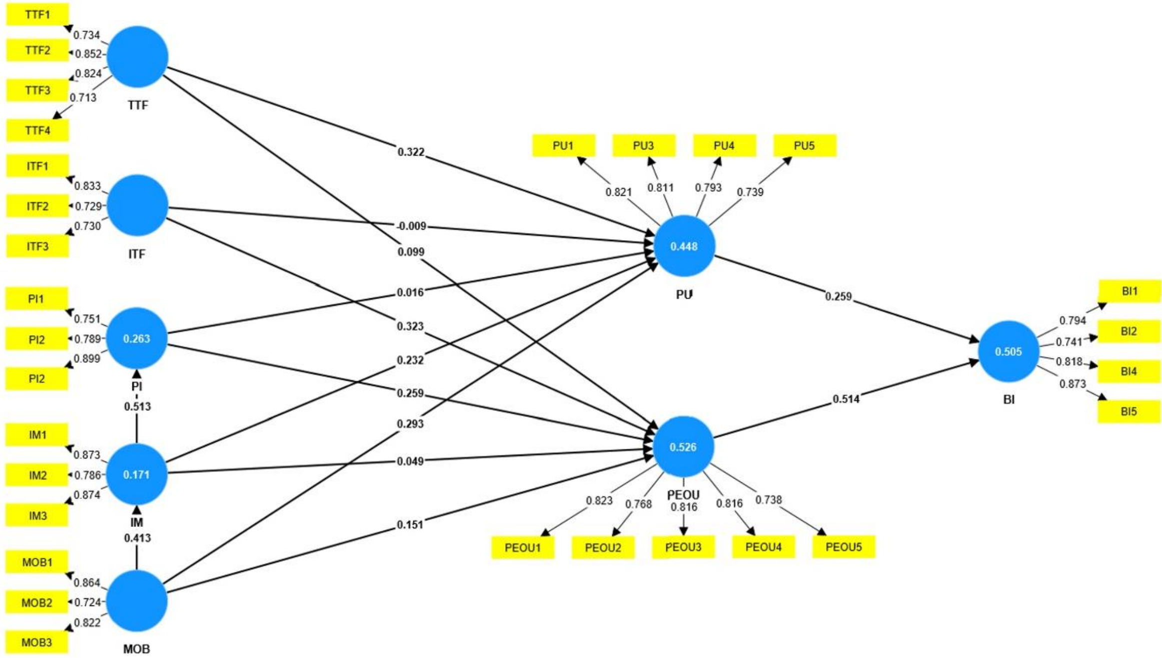

Figure 5.1: PLS algorithm of the research model

The hypotheses findings can be seen in Table 5.6. The findings showed that TTF has a significant influence on PU (β = 0.326, t = 2.885) and that TTF has an insignificant influence on PEOU (β = 0.099, t = 1.089). Hence, H1 was accepted and H2 was rejected. The findings revealed that ITF has an insignificant influence on PU (β = -0.008, t = 0.065) and ITF has a significant influence on PEOU (β = 0.325, t = 3.662). Therefore, H3 was rejected, while H4 was accepted. Similarly, the findings also indicated that the PI has an insignificant influence on PU (β = 0.022, t = 0.022) and that the PI has a significant influence on PEOU (β = 0.252, t = 2.743). Thus, H5 was rejected and H6 was accepted. Further, the findings showed that IM has a significant influence on PU (β = 0.229, t = 0.229) and IM has an insignificant influence on PEOU (β = 0.051, t = 0.051). Hence, H7 was accepted, while H8 was rejected. The findings displayed that MOB has a significant influence on PU (β = 0.289, t = 3.610), and MOB also has a significant influence on PEOU (β = 0.157, t = 2.276). Therefore, H9 and H10 were accepted. The findings indicated that IM has a significant influence on PI (β = 0.515, t = 9.631), so H11 is accepted. The findings displayed that MOB has a significant influence on IM (β = 0.418, t = 5.614); hence, H12 is accepted. The results showed that PU has a significant influence on BI (β = 0.265, t = 3.571) and PEOU also has a significant influence on BI (β = 0.512, t = 7.631). Therefore, H13 and H14 were accepted.

Table 5.6 Hypotheses Testing Results

Hypothesis	Relationship	Std. Beta	t-value	p-value	Decision
H1	TTF -> PU	0.326	2.885	0.004*	Supported
H2	TTF -> PEOU	0.099	1.089	0.276	Rejected
H3	ITF -> PU	-0.008	0.065	0.949	Rejected
H4	ITF -> PEOU	0.325	3.662	0.000*	Supported
H5	PI -> PU	0.022	0.188	0.851	Rejected
H6	PI -> PEOU	0.252	2.743	0.006*	Supported
H7	IM -> PU	0.229	2.888	0.004*	Supported
H8	IM -> PEOU	0.051	0.657	0.511	Rejected
H9	MOB -> PU	0.289	3.610	0.000*	Supported
H10	MOB -> PEOU	0.157	2.276	0.023*	Supported
H11	IM -> PI	0.515	9.631	0.000*	Supported
H12	MOB -> IM	0.418	5.614	0.000*	Supported
H13	PU -> BI	0.265	3.571	0.000*	Supported
H14	PEOU -> BI	0.512	7.631	0.000*	Supported

*Note: *p<0.05; significant*

Regarding the R2 outcomes, Figure 5.1 reveals that the combined factors of task technology fit, individual technology fit, perceived interaction, perceived immersion, and perceived mobility account for 52.6% of the variation in perceived ease of use. Notably, perceived ease of use alongside perceived usefulness accounts for 50.5% of the variation in the behavioural intention to adopt augmented reality devices for use in CSI training. Given the established R2 threshold values, the R2 figures derived from this suggested model are deemed to be satisfactory.

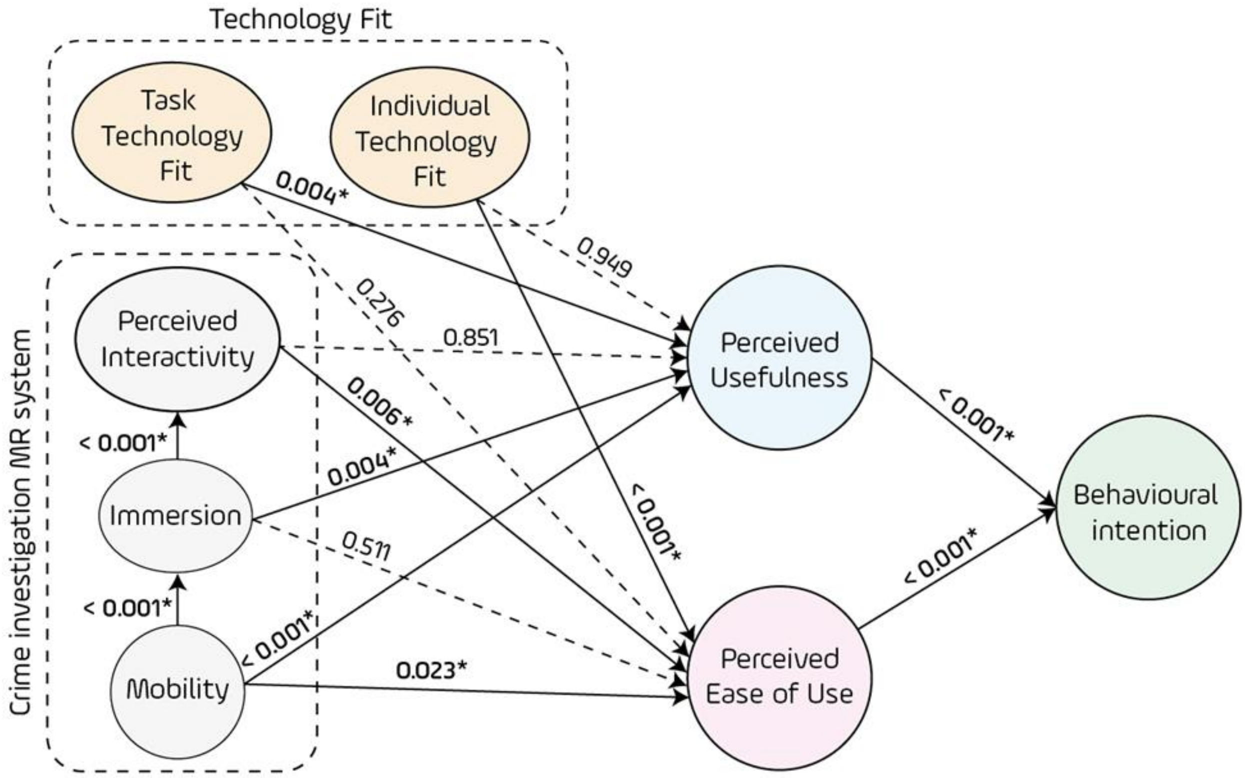

Figure 5.2: Research Model Describes Hypothesis Testing

5.4 Qualitative Analysis

In the qualitative analysis, senior investigators and police academy experts were involved in conducting the validation and testing of the required AR system. The validation and testing demonstrated that the system is indeed valid for training young investigators. It ensures that the correct sequence of investigation practices aligns with the established standard procedure of police investigations. The first stage involved a training module for police academy experts on using Microsoft HoloLens 2.0. The AR headsets were provided to see and interact with a virtual scanned crime scene and to explore the crime scene, predict the crime's nature, understand the incident story, and collect the evidence. The most crucial task was to collect the virtual evidence and send it to the virtual lab. Then, find the criminal among the different suspects and solve the case. This task needed to be completed in approximately 20 minutes. Following that the questionnaire was then filled out and interviews were conducted with open-ended questions. A semi-structured interview was conducted.

The following questions were asked during the interview:

1. Please describe the scanned environment of the crime scene.

2. Please describe how you feel in these immersive augmented realities.
3. Please describe your experience while performing the tasks.
4. Please describe what you think about the whole experience.
5. Please discuss what you think of using this application to archive crime scenes to be visualised in court.

5.4.1 Analysis Technique

For this study, thematic analysis was employed to analyse the expert interview findings. Thematic analysis is used to create themes that capture a phenomenon that has been previously clarified (Ryan et al., 2000). Additionally, a 'word cloud' was utilised to depict the study objectives.

5.4.2 Statistical Software

NVivo was employed to conduct the thematic analysis. This software supports various data formats such as audio files, videos, digital photos, word documents, PDF, spreadsheets, rich text, plain text and web and social media data. The interviews were audio-recorded, transcribed, and analysed using NVivo software, facilitating a comprehensive examination of the data.

5.4.3 Findings

The analysis unveiled four main themes which were also represented in NVIVO as codes (Table 5.7). Additionally, five themes emerged from the interview questions, capturing the diverse aspects explored during the interviews.

Table 5.7. Key themes with subthemes

Crime scenes and their scanned environment
• Actual crime scene
• Low crime rates
• Different crime scenes
• Crime tool
• Crime scene location
• Crime scene investigation process
• Scanned environment
Immersive augmented realities
• Real crime scene

• Unique experiment • Evidence collection process • Real investigation • Clear vision • Middle of the crime scene • Comfortable
Tasks
• Advance training • User friendly • Crime scene investigation • Direct instruction
Whole experience
• Training • Helpful to examine the crime scene
Crime scenes to be visualised in court
• Helpful to judge or jury • Saved time

The themes discussed the interview questions one by one, in which subthemes were covered under the key themes. Quotes from experts were used to illustrate the themes, providing supporting evidence for the insights presented.

5.4.3.1 Crime scenes and their scanned environments

The first interview question involved describing the scanned environment of the crime scene. In the findings, the experts provided varying opinions. The first main theme was further divided into seven subthemes.

The scanned environment

Many participants discussed the scanned environment. One participant mentioned, 'The digitally scanned environment with the laser and the locations and spread of the evidence were present clearly and easily, and the closest thing is that it is realistic, and the work done in this program, frankly, is something I did not expect with all this creativity'. Another expert expressed their thoughts on the bone scanned environment, stating: ‘The topic is about the bone scanned environment, as I found it to be a very excellent idea, especially that you can teach people the different types of environments in which the crime scene is located. For example, on land, at sea, in the mountains, at school or in the garden, it can be changed, and this idea cannot be applied, except through the bone-scanned environment and this great idea will help many people through this program. One expert commented about its quality and accuracy, stating: ‘The scanned environment is of suitable quality and accuracy. The scanned environment was accurate and showed a very good representation of the crime scene. The system was good enough that it could be used in different environments to show accurate visualisation’. One expert offered their perspective on the improvement, remarking: ‘The graphics were of good quality but can be improved. There can be more areas to explore, such as inside or under furniture and the outside environment, looking for entry and exits for the criminal and finding evidence outside’. Another expert provided their insights, stating, ‘The scanned environment of a crime scene is one of the technology implementations that gives law enforcement the full image of the crime scene in detail, which could help to minimise any argument by lawyers in court. Scanned environments are one of the technologies that need to be approved as essential to be used in crime scenes.

Actual crime scene

An expert commented about the first interview question, ‘The system was able to show an accurate and comprehensive depiction of the evidence collection process without causing any risk of contamination or breach of security at an actual crime scene’.

Low crime rates

One candidate stated, ‘It also allows the teaching of new investigators to correctly navigate and collect evidence through different types of environments, weather, conditions and locations, with the added advantage of being able to do it from anywhere, such as training institutions or cities with low crime rates. The opportunity to access crime scenes as they can be accurately scanned and visualised through this program is a significant benefit.

Different crime scenes

Another participant commented, ‘The virtual reality program designed a realistic environment to experience a crime scene. It is a good system, especially as a training program, as it provides an opportunity for trainees to observe different crime scenes and experience what it is like to be inside a crime scene'.

Crime tool

Another expert stated, 'This is the beginning of very important research at this time to improve the work of examining the crime scene and an environment that is allowed to be more accurate and comprehensive in the detail of a crime scene without deficiencies or shortcomings in the examination. At the scene of the accident, which must be accurate, if the upper surfaces are flawed, it is possible that some material traces could be below the furniture and present at the scene of the accident, or for the presence of the perpetrator to hide the crime tool under the furniture or in it when it is not visible to the naked eyes'.

Crime scene location

One expert stated, 'The scanning was very good, and it can be used to teach students and trainees in different types of environments and crime scene locations while staying in the same location. Sometimes all locations cannot be accessed, and this will help train about how to work in those places.

Crime scene investigation process

Another expert said, 'The program allowed for a close-to-real experience of being involved in a crime scene investigation process, as real-life environments and locations can be scanned and visualised'.

The word cloud indicates how frequently used words matched the study. This visualisation was extremely helpful in familiarising with the questions asked in the interview. Words were accumulated in the form of a cloud, and the max font size correlated with the most prevalent occurrence of the same word in coding node references. This visualisation allows us to easily demonstrate the main themes in which, if focused on the bold words, these words describe the keyword responses of police academy experts on crime scenes and their scanned environment (Figure 5.3).

Figure 5.3: Word cloud of the crime scene and scanned environment

5.4.3.2 Immersive augmented realities

The second interview question focused on describing how participants felt in these immersive augmented realities. The second key theme was then subdivided into seven subthemes.

Real crime scene

One expert stated, 'The existing environment and how it was combined with the truth as if it were real in a mixed way, made it easy for me to see the crime scene in a way that makes me feel I am actually present in it'. Another person said, 'It felt real and like I was in the scene. It allowed easy movement between the different rooms and guided the way, so it felt very well instructed'. One expert stated, 'It was a good experience and helped to feel immersed in the program. It felt like being at a real crime scene'. Another expert stated, 'I feel that I am in reality and all that exists is real and simulates reality'.

Unique experiment

One expert stated, 'It is a unique and successful experiment in all respects, and it must be adopted in the near future by all crime scene experts. Any potential negative aspects should be addressed to further enhance its effectiveness'.

Evidence collection process

An expert stated, ‘The ability to visualise a crime scene virtually and being guided through the evidence collection process made it easier to understand how a crime scene should be navigated’.

Real investigation

One expert said, ‘I felt like I was conducting a real investigation while I was in my office’.

Clear vision

An expert commented, ‘It gives the trainee an appropriate feeling and vision, creating a sensation similar to being in a real-life setting’.

Middle of the crime scene

One participant stated, ‘The 3D images and videos let me feel like I am in the middle of the crime scene and let me rotate 360 degrees and see whatever I was looking for especially since we can only investigate a crime scene once. These immersive augmented realities let you revisit crime scenes whenever and however you want.’. Another participant stated, ‘There is a feeling of being at the scene of the accident in 3D, where you can move between the monuments and the accident scene easily. It is also easy to view all the results of the laboratories, quickly.

Comfortable

One expert said that it was ‘comfortable and easy to use’.

Figure 5.4: Word cloud of immersive AR

Figure 5.4 illustrates the visualisation of the word cloud. This visualisation aids clearly and straightforwardly, showcasing the main themes. By focusing on the bold words, these key responses describe the feelings of police academy experts in immersive AR.

5.4.3.3 Tasks

The third interview question revolved around describing the participant's experience while performing the tasks. As a result, the third key theme was further divided into four subthemes.

Advance training

One participant stated, 'From my experience and what I watched from the video, I find that assembling the traces, explaining the crime scene, and navigating in it is easier, and this is the opposite of what we are suffering from now. Navigating inside the accident, its description, its results and even the number of traces, significantly facilitates the detection process at the crime scene, and it is an advanced training'.

User friendly

One expert stated that it was 'easy to learn and useful to be used in Kuwait'. Other participants remarked, 'It was easy to perform the tasks because there were a lot of hints and prompts to show where to look and what to do next. The difficulty level was easy, and all the instructions were easy to follow'. Another expert described, 'The application is user friendly, and it is easy to find what you are looking for, especially the tools that let you investigate the scene with comfort'.

Crime scene investigation

Many experts provided their opinions on it, and one expert said, 'A realistic and dazzling feeling that very much helps me to investigate and discuss the crime, to know the locations of the evidence and to link them in the future in a way that facilitates the crime scene inspectors writing their report, analysing it and linking the evidence'. Another said, 'This program will greatly help people who work on crime scenes by allowing them to get a sense of inspecting the crime scene and knowing how to deal with the different environments in which the crime scene is located. It will greatly help in developing science, especially for beginners and teachers alike'. Regarding the investigation of a crime scene, another participant said, 'As a tool for investigating a real crime, it is not appropriate, but as a training tool or as a means of presentation to the investigation and judiciary authorities, it is excellent, especially since a crime scene is difficult to maintain, as it is throughout the investigation and litigation period'. One expert commented, 'The program will be invaluable in helping investigators, training centres and law enforcement agencies to work on crime scenes by being able to inspect the crime scene, practising the collection of evidence, knowing how to work with different environments and using the records in court'. Someone called it realistic, saying, 'It is a realistic process that helps to investigate the crime, identify the evidence and keep records in a way that makes the evidence admissible in court'.

Direct instruction

One expert stated, 'While performing the task, the instructions were good and very direct. This helped me to follow which steps to take next and to move through the scene very quickly. There could be a more difficult option with fewer instructions so the participant can try to find things independently'. Another expert commented, 'The tasks were all guided and there were a lot of instructions, so when I got stuck, I was able to continue using the instructions. The steps were easy to follow'.

Figure 5.5: Word cloud of experience while performing tasks

Figure 5.5 shows the visualisation of the word cloud. This visualisation creates an easy way to demonstrate main themes in which, if focusing on bold words, these words describe the keyword responses to police academy experts' experiences while performing tasks.

5.4.3.4 Whole experience

The fourth interview question was focused on describing participant's overall thoughts on the whole experience. Consequently, the fourth key theme was further divided into two subthemes.

Training

Many participants gave their opinions about the whole experience and talked about it as a training tool, in which one individual remarked 'It is a good experience that will make training much easier with the ability to repeat the case as many times as possible and making a variety of crime scenes with minimum space', and another participant describes it as 'a unique and one-of-a-kind experience which eases the crime investigation training'. One person stated, 'As an excellent training tool, it contributes to the transfer of information to the trainee in a way that is smoother and closer to reality and prints your memory and acquisition of information, even if it is not sufficient on its own as a training method'. One participant highlighted the training sessions as follows: ‘A real crime scene cannot be used as a training session due to the importance of the evidence in real cases. However, this kind of application lets you hold training sessions on real cases without interrupting the evidence’. Someone said, ‘It was a good experience and very educational. It helped to understand how crime scene investigators can be taught in the near future and how technology can be used in this field starting at the training stage’. One participant expressed, ‘It is a very good source of training and teaching tools. Even for experienced investigators, it is a good revisitation of the basics, and it can be developed for more stages and higher difficulty’. One participant stated that, as a training simulation, ‘it was a good experience, especially as a training simulation. It will be very helpful in training new crime scene investigators. It can help teach the whole process of preserving the crime scene, where to look for evidence and how to collect and upload them to the system’. Another individual said, ‘The system is a good addition to training new crime scene investigators in processing scenes without having to visit the scenes themselves’.

Helpful in examining the crime scene.

According to an expert, ‘This is an excellent and wonderful experience that provides a qualitative leap in examining the crime scene and avoids delay in addressing the specialised laboratories for required tasks or communication with relevant experts present at the crime scene. We highly recommend it’.

Another participant stated, ‘Applying the tool and letting others assist in collecting evidence and referring to it whenever necessary. I believe it is an important experience and helps the investigation authorities answer many of their questions regarding how to link the evidence’.

One person said, ‘It will help the teacher to feel the reality of the accident and help him to know the difference in the crime environments. It also highlights how the researcher deals with each crime scene uniquely. Additionally, it assists the teacher in better understanding students’.

Another expert commented, ‘It is a very interesting tool that allows you to move around the crime scene easily and smoothly’.

Another expert described his experience: ‘It was different and unique. The technology and idea can be adopted in the near future by all teaching centres, police, crime scene investigators, etc., to train more people in different and new environments, making them familiar with various cases.

Figure 1.6: Word cloud of thought on the whole experience

Figure 5.6 displays the visualisation of the word cloud. This visualisation provides a straightforward way to demonstrate the main themes. By focusing on the bold words, these keyword responses describe the thoughts of police academy experts on the whole experience.

5.4.3.5 Crime scenes to be visualised in court.

The fifth interview question focused on participants' thoughts about using this application to archive crime scenes for visualisation in court. As a result, the fifth key theme was further divided into two subthemes.

Helpful to judge or jury

One expert said, ‘I think that the program has made things very easy for the judge and the investigator, as they will live at the crime scene virtually in a way that makes it easier for them to understand the report of the crime scene inspectors. This leaves no doubt for them that the report is scientifically and correctly built and helps them in making the right decision’.

Another participant stated, ‘The ability to allow judges and juries to view the crime scene exactly as seen by the crime scene investigators and prosecutors virtually will help in establishing the validity of the acquired evidence presented in court. It will also make it easier for them to understand the circumstances surrounding the case and reach an informed decision'.

One individual remarked, 'It will also allow the judge and jury to inspect the scene virtually, without having to go to the actual crime scene. This will leave little to no space for doubt when trying to rebuild the events/conditions/means around the perpetration of the crime'.

An expert believed, 'It will help a lot in court cases because now only pictures or videos are used in court, but using a scanned environment will help the judge and jury and everyone involved understand the scene better and link all the evidence'.

Another commented, 'It is a good system to allow the court to understand all the information related to the crime scene. It can also help everyone involved with the case have the same information and visualise how the original crime scene looked and what exactly happened'.

Another person said that 'it is ideal for court archives and court judges, especially with cold cases reopened 20–25 years back'.

One person stated, 'This technology can be used to serve the archiving system with accuracy and ease. It does not take up much space in the programs or the archiving place, and it can be in the courtroom and enable judges to view the crime scene without physically moving to it'.

Saved time

One expert said, 'Due to the fact that court cases are a long process, the crime scene cannot be preserved the whole time. It is also not possible to explain everything in the scene exactly in court and now mostly pictures are used. But using a system like this will help the court understand and visualise the crime scene a lot better and it will make it easier to follow exactly what happened during the crime'.

Another person stated, 'Since the preservation of the actual crime scene can be difficult to maintain throughout the investigation and litigation period and may take from months to years, it will provide invaluable aspects of preservation and maintenance of the integrity of evidence'.

Figure 5.7: Word cloud of a crime scene to be visualised in court

Figure 5.7 shows the visualisation of the word cloud. This representation provides an easy way to demonstrate the main themes. By focusing on the bold words, these words describe the keyword responses of police academy experts using the AR investigation application to archive crime scenes for visualisation in court.

The thematic analysis also revealed correlations in Table 5.8. There was a positive correlation between immersive augmented realities and the crime scene along with their scanned environment (r=0.573). Additionally, a positive correlation was observed between tasks and immersive mixed realities (r=0.573), as well as between the whole experience and immersive augmented realities (r=0.568). Furthermore, there was a positive correlation between the crime scene to be visualised in court and immersive augmented realities (r=0.552). Moreover, a positive correlation was identified between the whole experience and the crime scene and its scanned environment (r=0.534). Additionally, there was a positive correlation between crime scenes to be visualised in court and tasks (r=0.510). Furthermore, a positive correlation was observed between tasks, the crime scene, and their scanned environment (r=0.50). Moreover, a positive correlation was identified between the whole experience and the tasks (r=0.497). Additionally, there was a positive correlation between the crime scene to be visualised in court and the crime scene and its scanned environment (r=0.473). Lastly, a positive correlation was observed between the crime scene to be visualised in court and the whole experience (r=0.451).

Table 5.8. Correlation coefficients between themes

Code A	Code B	Pearson correlation coefficient
Augmented mixed realities	Crime scenes and their scanned environment	0.573757
Tasks	Immersive augmented realities	0.573655
Whole experience	Immersive augmented realities	0.568481
Crime scenes to be visualised in court	Immersive augmented realities	0.552196
Whole experience	crime scenes and their scanned environment	0.534262
Crime scenes to be visualised in court	Tasks	0.510262
Tasks	crime scenes and their scanned environment	0.503730
Whole experience	Tasks	0.497442
Crime scenes to be visualised in court	Crime scenes and their scanned environment	0.473264
Crime scenes to be visualised in court	Whole experience	0.451286

5.5 Discussion

The progress in augmented reality technologies provides unprecedented opportunities for police trainees and emerging investigators by making virtual crime scenes readily accessible and facilitating training in investigative procedures. This technological platform enables remote, collaborative investigations, supported by visual and audio communication between trainees and experienced investigators (Piumsomboon et al., 2019). Traditional training in crime scene investigation often depends on fixed, predetermined environments that may not fully capture the complexities of actual crime scenes. In contrast, augmented reality can develop dynamic, fluid scenarios that can be adjusted in real time. Nonetheless, there exists a scarcity of knowledge concerning the application of these tools in the context of CSI training (Mayne and Green, 2020). Therefore, this current research seeks to explore particular variables expected to affect the readiness of police students to embrace these technologies for CSI educational objectives. To achieve this, an innovative theoretical model is presented that augments the technology acceptance model by integrating task-technology fit elements and essential features of augmented reality devices, specifically focusing on their portability, immersion, and interactivity.

The results of the present study confirm that technology task fit has a notable impact on perceived usefulness, indicating that the HoloHolmes Augmented Reality software is considered a valuable tool for the purposes of crime scene investigation during routine training and operations. Mayne and Green (2020) have emphasised that the relevance and effectiveness of technology for specific tasks serve as crucial factors influencing its acceptance and real-world deployment across different training settings for crime scene analysis. Several previous studies confirmed the robust and meaningful effect of TTF on PU across diverse contexts (Wu and Chen, 2017) (Chen, 2019) (Shih and Chen, 2013) (Rahi et al., 2021) (Yaakop et al., 2021) (Alkhwaldi and Abdulmuhsin, 2022). In contrast, a prior study by Vanduhe et al. (2020) yielded inconclusive data regarding the substantial impact of TTF on PU, despite observing a positive correlation between the two metrics. The significant relationship between technology task fit and perceived usefulness implies that the technology's close correspondence with the operational needs of crime scene investigation enhances its likelihood of being regarded as beneficial. This underlines the importance of collaborative design strategies that actively involve law enforcement experts in the iterative design process of the AR application. Future inquiries may delve into the specifics of this congruence, such as whether features like real-time data analytics or cooperative user interfaces offer varying levels of perceived usefulness.

The current research findings suggest that TTF lacks a significant impact on PEOU, hence nullifying the theorised connection between TTF and PEOU. On the other hand, a positive correlation was noted between TTF and PEOU. This concurs with previous studies, specifically those conducted by Yen et al. (2010) and Ishfaq and Mengxing (2021), investigating technology adoption. Both of these prior studies rejected any relationship between TTF and PEOU, thereby dismissing the postulated relationship between these variables. In the context of augmented reality technology, when it aligns well with a task technology fit, it does not necessarily influence enhancing the PEOU for AR devices or their applications. A proposition worthy of additional investigation may be that the technological complexities introduced by well-fitting technology could potentially be counterbalanced by its perceived usefulness, making the ease of use a principal factor.

The findings of the research, executed by police academy students, demonstrated that the effect of ITF on PU was not significant, thereby rejecting the proposed relationship between these variables. This aligns with previous research employing varied technologies in diverse settings, which also concluded that ITF does not significantly influence PU, thereby rejecting the hypothesized relationship (Wu and Chen, 2017) (Alkhwaldi and Abdulmuhsin, 2022). Conversely, authors have suggested in different contexts that ITF alone may not suffice to achieve the level of PU necessary for broad technology acceptance (Wu and Chen, 2017). In contrast, the present study found that ITF has a significant impact on PEOU, thus validating the investigated relationship between ITF and PEOU. This is consistent with earlier studies that employed different technologies (Wu and Chen, 2017) (Yaakop et al., 2021) (Alkhwaldi and Abdulmuhsin, 2022). However, this finding contradicts another study that concluded ITF has no meaningful impact on PEOU, thereby rejecting the explored correlation (Kurniawan et al., 2021). In the context of augmented reality and its applications, despite the students' novel user experience, the study emphasizes the lack of a positive correlation and posits that ITF does not significantly affect PEOU (Kurniawan et al., 2021). The nonsignificant association between Individual Task Fit and perceived usefulness may imply that personal competence or suitability for crime scene investigation tasks does not heavily affect the perceived ease of use of the technology. Nevertheless, its significant effect on perceived ease of use suggests that previous experience in crime scene investigations could make navigating the AR interface more intuitive.

In terms of perceived interaction for the AR application, the study reveals that PI does not have a significant impact on PU, thus validating the rejection of the hypothesized relationship between PI and PU. Existing literature discourse lacks a unified consensus on the extent to which PI notably influences PU. The complex nature of interactivity, particularly in the field of AR/VR technologies, might add to the ambiguity in its perceived usefulness (Park and Yoo, 2020). On the contrary, the study did confirm that the PI of the AR device and its software significantly influences PEOU, thus the explored relationship between PI and PEOU is accepted. This is in agreement with previous studies that have affirmed the significant influence of PEOU on PI, consequently validating the proposed linkage between PI and PEOU (Rahmi et al., 2018) (Huang and Liaw, 2018). As a result, the research establishes a one-way dependency, suggesting that PEOU acts as a predictor for PI, rather than vice versa (Shankar and Datta, 2018). While perceived interactivity did not significantly impact perceived usefulness, its considerable influence on perceived ease of use warrants additional scholarly inquiry. This could suggest that increased levels of interactivity do not automatically offer functional benefits but do contribute to a more intuitive and engaging user experience.

Concerning the construct of immersion, the research validates a significant influence of IM on PU, confirming the hypothesised relationship between IM and PU. On the other hand, existing scholarly work lacks in providing an exhaustive comprehension of IM's effect on PU, especially within the context of training via AR/VR technologies; though some studies do exist in different disciplines (Huang et al., 2016) (Barrett et al., 2021). The immersion concept presents a complex variable that complicates the quantification of its direct association with PU, resulting in the challenge of the established relationship between IM and PU in prior research. In the present study, it was observed that IM does not significantly affect the PEOU, leading to the rejection of the proposed link between IM and PEOU. These findings are consistent with earlier research that verified the triviality of IM's impact on PEOU (Huang et al., 2016) (Xie et al., 2022). Moreover, no substantiating evidence could be located in the current body of literature to validate a significant impact of IM on PEOU, particularly in the context of training through augmented reality technologies. In contrast, previous work by Ghobadi et al. (2022) detected a strong relationship between IM and PEOU, suggesting that heightened immersion levels aid users in embracing new technologies, consequently boosting PEOU. In scenarios of increased immersion, technology is deemed user-centric and contextually relevant, highlighting the potential importance of immersion in determining ease of use. Ghobadi et al. (2022) further reported a strong positive correlation between IM and PEOU, indicating a direct positive relationship between IM and PEOU.

This research further establishes that IM positively correlates with PI, thus validating the proposed relationship between IM and PI. Notably, no existing studies were available to either confirm or reject this correlation. The implications of these results are that technologies incorporating AR, VR, or MR can positively affect user perceptions of interactivity, thereby enhancing their learning experiences within new tech landscapes. Consequently, the level of immersion becomes a pivotal factor in shaping user perceptions regarding a technology's interactive potential, which in turn affects its rate of utilization and adoption. Technologies that offer profound immersion while catering to user requirements are more likely to experience elevated adoption and usage rates (Petersen et al., 2022). The considerable influence of immersion on perceived usefulness and interactivity, but not on ease of use, can be explained by its role in simulating a 'real-world' training context. This prompts critical inquiries concerning the ideal degree of immersion needed for efficacious training, which merits additional empirical research.

Concerning mobility, this study confirmed that MOB has a significant influence on PU, thus accepting the hypnotised relationship between MOB and PU. Despite the lack of existing literature on MOB's impact on PU specifically in the realm of augmented reality device training, a handful of studies have established this relationship in varying technological contexts across diverse sectors (Huang et al., 2007) (Tjandra et al., 2022). Utilizing mobile technologies may entail trade-offs in certain areas, requiring increased effort for effective deployment. As a result, even with potential advantages in fields like criminal investigations, mobility is considered detrimental to PU according to current academic insights, thereby highlighting that it should not be an emphasized aspect or area of concentration (Lwoga and Lwoga, 2017). Additionally, this study verifies that MOB has a significant effect on PEOU, thus validating the hypnotised relationship between MOB and PEOU. Prior studies have confirmed the relationship between MOB and PEOU across different technological platforms (Othman et al., 2022) (Li et al., 2019) (Kalinic and Marinkovic, 2016). In this specific context, the ability of young police investigators to navigate a digitally scanned crime scene is vital. Therefore, these outcomes affirm that the mobility aspect of augmented reality devices influences both the perceived usefulness and the ease of use of the AR application, facilitating comprehension of the application and contributing to a user-friendly experience.

The outcomes of this research indicate a significant influence of MOB on IM, confirming the investigated relationship between MOB and IM. Despite the lack of prior research on this specific relationship, this study demonstrated that the privilege of mobility in augmented reality devices notably improves the sensed interactivity between users and virtual content. This has implications for the methods young investigators use for crime scene exploration, which were employed in this research. The influence of mobility on both perceived usefulness and ease of use is crucial, particularly in the realm of crime scene examinations that often necessitate quick adaptation and responses. Consequently, forthcoming AR applications should prioritize mobile, lightweight solutions without sacrificing computational power.

In accordance with previous scholarly works, this study revealed that PU significantly influences BI, thereby substantiating the postulated connection between PU and BI. PU emerged as a pivotal factor in shaping BI, particularly in the scenario of student interaction with e-portfolios, thus confirming its critical role (Abdullah et al., 2016). While several existing studies have affirmed this correlation across various technologies (Yen et al., 2010) (Vanduhe et al., 2020) (Wu and Chen, 2017) (Yaakop et al., 2021) none have examined this relationship in the context of mixed reality. Additionally, this research confirms that PEOU also has a significant influence on BI, endorsing the proposition that the relationship between PEOU and BI is significant. These findings are consistent with prior studies that emphasised the significant influence of PEOU on BI (Yen et al., 2010) (Vanduhe et al., 2020) (Rahi et al., 2021) (Yaakop et al., 2021). Therefore, it is essential for emerging technologies to be designed as user-friendly to encourage user adoption and acceptance. When technology is perceived as easy to use, it reduces barriers to its implementation, thereby amplifying its relevance to users in completing their tasks. Accordingly, this elevates the probability of technology adoption. Investigating the intention to utilize the technology and the actual usage behaviour are key components in assessing user acceptance (Verma and Sinha, 2017). Both perceived usefulness and ease of use were determined to substantially influence the behavioural intention to adopt the AR system, suggesting that for mass adoption, AR applications need to be not just task-appropriate but also user-friendly.

The findings of the interview results described the scanned environment of the crime scene in which experts found that the environment was good, accurate and showed an excellent representation of the crime scene. Experts have defined the scanned environment as one of the essential technologies that need to be approved for use in crime scenes. The findings indicated that a scanned environment allows new teachers to correctly navigate and collect evidence through different types of environments, weather conditions, and locations with the added advantage of being able to do it from anywhere, such as training institutions or cities with low crime rates. The VR system was designed to create a realistic environment to experience a crime scene allowing for a close-to-real experience of being involved in a crime scene investigation process. Real-life environments and locations can be scanned and visualised, enhancing the immersive environment. The word cloud confirmed that crime scenes with scanned environments were aligned with the quantitative analysis.

The findings revealed that experts felt fully immersed in the VR program, making them feel like they were part of a real crime scene. They expressed that this unique and successful experiment should be adopted in the future as it significantly aids in evidence collection and understanding the crime scene dynamics. The use of 3D images and videos allows users to feel as though they are physically present in the crime scene, offering a 360-degree view and the flexibility to revisit the scene multiple times. This immersive AR experience enables a comprehensive examination of the evidence, making it an invaluable tool for investigations that may only have one opportunity for examination.

The word cloud also defined the responses and feelings of the experts in immersive AR. The result of police academy experts indicated that the tasks were easy to learn and are likely to be beneficial in Kuwait. The realistic process facilitated crime investigation, evidence identification, and record-keeping in a manner that ensures admissibility in court. The clear and straightforward directions helped guide the experts through each step, allowing for efficient movement and investigation of the crime scene.

Furthermore, the findings also highlighted that experience was favourable and significantly enhanced the training processes. The ability to repeat training sessions multiple times and create variations of crime scenes in a confined space was particularly advantageous, making the training more effective and efficient. It was an excellent and wonderful experience that represents a significant advancement in crime scene investigations, minimizing delays in addressing specialized laboratories or communicating with relevant experts. The word cloud validated that the responses of police academy experts' thoughts on the whole experience matched the quantitative study. Additionally, the findings highlighted the benefit of using AR applications in court proceedings, enabling judges and juries to view the crime scene exactly as seen by the crime scene investigators and prosecutors. This aids in establishing the credibility of presented evidence and facilitates a better understanding of the case for informed decision-making. The AR technology also proves valuable for archiving, ensuring accuracy and ease of access. Given the lengthy nature of court cases and the challenges of preserving crime scenes indefinitely, AR applications offer a time-saving and immersive solution. The word cloud further confirmed that the AR application provides a clear image of the crime scene and aligns with the quantitative findings.

The findings further revealed several positive correlations within the study. There were positive correlations between the crime scene and their scanned environment, immersive AR, the whole experience, and the crime scene to be visualised in court. Additionally, a positive correlation was observed between immersive AR and tasks, the whole experience, and the crime scene to be visualised in court.

5.6 Conclusion

In conclusion, this study successfully developed a systematic AR application using Microsoft HoloLens 2 to enhance the young investigators' practical investigation skills in crime scenes. The research incorporated five external factors from the technology acceptance model that is integrated with task technology fit models and utilised a mixed-methods approach. The quantitative phase employed SmartPLS 4.0 and structural equation modelling to analyse the relationships between the research model's constructs.

The findings indicated that the majority of male police academy participants were aged between 18 and 60 years, with a significant number holding bachelor's degrees. In contrast, the qualitative phase revealed that male police academy experts were predominantly aged between 40 and 60 and possessed a higher level of education.

The hypotheses testing supported the importance of perceived usefulness in the TAM, along with other factors such as task technology fit, immersion, mobility, and behavioural intention. Additionally, perceived ease of use demonstrated the potential to increase technology adoption when combined with TTF, IM, MOB, and BI. The study identified positive correlations between the constructs, although some negative correlations were observed in previous research.

The expert interviews highlighted that the AR application provided an accurate and immersive representation of the crime scene, facilitating evidence collection in various environments. Experts reported feeling engaged and acknowledged the application's efficacy in crime investigation, making training more accessible and contributing to fair outcomes. The AR application can be extended its beneficiary to improve the understanding and visualisation of the crime scene for juries and judges, ultimately saving time in decision-making processes.

Overall, the qualitative data complemented the quantitative findings, providing a comprehensive understanding to fulfil the study's objectives.

CHAPTER 6
CONCLUSION AND FUTURE STUDIES

6.1 Introduction

Theoretical contributions of this study include the integration of TAM factors with AR technology to better understand its adoption and acceptance among police academy participants. By exploring the relationships between perceived usefulness, task technology fit, image manipulation, mobility, and behavioural intention, we have gained valuable insights into the factors influencing the acceptance of AR applications in crime scene investigations. This enhances our understanding of technology acceptance in law enforcement contexts and paves the way for future research in this area.

The practical contributions of this study lie in the development and implementation of the AR application itself. The application's realistic environment allows investigators to experience crime scenes more effectively, aiding in evidence collection and navigation. This has the potential to improve the efficiency and accuracy of crime scene investigations, leading to more reliable and comprehensive outcomes. Furthermore, the application's use in court settings can enhance judges' and juries' understanding of the crime scene, leading to informed decision-making and potentially reducing the time required for trial processes.

Overall, this study's theoretical and practical contributions provide valuable insights into the potential benefits of AR technology in crime scene investigations. The developed AR application and its positive reception among experts highlight its usefulness and potential impact on law enforcement practices. As such, this research serves as a foundation for future studies and the advancement of AR applications in the field of criminal investigation and other related domains.

In addition to the conclusion, the section on future studies explores the possibilities for further research and development. It considers the limitations of the current study and identifies areas that warrant further investigation. Future studies can build upon the findings of the current research, addressing its limitations and expanding on the research questions that remain unanswered.

By suggesting potential future research directions, this section highlights the dynamic nature of the field and emphasises the need for continuous exploration. It encourages researchers to delve deeper into the subject matter, explore new methodologies, or investigate related aspects that have not been thoroughly examined. Future studies provide an opportunity for researchers to contribute to the field by filling gaps in knowledge, refining existing theories, or addressing emerging challenges.

6.2 Overall Conclusion

This study described investigations through the development of a systematic AR application—represented in Microsoft HoloLens 2—to enhance the efficiency of their investigation practices and to achieve the correct and accurate investigation methods at the real crime scene. This study included five external factors of TAM: TTF, ITF, IM, PI, MOB, PEOU, PU and BI.

The quantitative phase described the questionnaire findings using SmartPLS 4.0, while the qualitative phase described the interview findings. In the quantitative phase, partial least squares structural equation modelling was used to explore the relationship between the constructs in the proposed research model. From the quantitative results of 160 police academy participants, it was found that the majority of male students belonged to the age group of 18–60 years, while most of the students had bachelor's degrees. The qualitative data, on the other hand, showed slightly different results, in which most of the police academy male experts were in the age group of 40–60 with a higher level of education. Validation and hypothesis testing were conducted and there were no concerns regarding the assessment of discriminant validity in this study. The hypotheses testing concluded that PU was one of the core aspects of the TAM and most of the participants/students supported the hypothesis with TTF, IM, MOB and BI. PEOU has the potential to increase how many people may use technology with TTF, IM, MOB and BI. The study concluded that there were positive correlations between constructs, while some showed negative correlations in the previous study. The experts' interview findings concluded that the scanned environment of the crime scene was good and showed an excellent representation of the crime scene. It was helpful to collect evidence about different types of environments. The results further showed that the experts felt real and immersive in the AR environment. The AR application offered a remarkable 3D experience, making experts feel as though they were present at the crime scene while performing their tasks. They emphasised that the application significantly contributed to crime investigation and facilitated training, ultimately leading to fair outcomes. Its immersive nature enhanced engagement and understanding, making it easier for juries and judges to visualise the crime scene, ultimately expediting the decision-making process. The use of AR technology proved to be a valuable tool in the investigation and legal proceedings, providing a novel and effective approach to crime scene analysis and visualisation.

Indeed, the qualitative data played a crucial role in complementing and enhancing the quantitative findings. It provided deeper insights, context, and a more comprehensive understanding of the research aim and objectives. Through the qualitative interviews, experts were able to express their experiences, perceptions, and feedback in their own words, enriching the interpretation of the quantitative results.

By combining both qualitative and quantitative data, the study achieved a more robust and well-rounded analysis. The qualitative data helped to contextualize the statistical findings, shed light on participants' perspectives, and offer valuable explanations for observed correlations and relationships. This synergy between qualitative and quantitative methods allowed for a more nuanced interpretation of the results and a more accurate fulfilment of the study's objectives.

6.3 Research Contribution

6.3.1 Theoretical Contributions

The theoretical contributions of this research are centred on the exploration using technologies such as a augmented reality Learning Environment and training venue for crime scene investigation. The study delves into the theoretical foundations of using AR technology, specifically the HoloLens device, in the context of training crime scene investigators. It examines existing literature on AR and its potential applications in various domains and then applies these theories to the specific field of forensic investigations.

The research establishes a theoretical framework that highlights the benefits and possibilities of AR in crime scene investigation. It identifies key theoretical constructs, such as spatial cognition, situational awareness, and cognitive load, and examines how AR can enhance these factors in the training process. By integrating theories from fields such as human-computer interaction, cognitive psychology, and education, the study provides a solid foundation for understanding the theoretical underpinnings of AR-enhanced crime scene investigation training.

6.3.2 Practical Contributions

The practical contributions of this research lie in the development and implementation of an Augmented Reality Learning Environment for crime scene investigation training. The study goes beyond theoretical discussions and actively creates a practical solution that can be utilised by crime scene investigators and training institutions. It involves the design and development of a software application that simulates crime scenes which can be accessed through the HoloLens AR device.

The research contributes by demonstrating the feasibility and effectiveness of using AR technology, specifically HoloLens 2, in training crime scene investigators. It provides insights into the practical considerations, such as user interface design, interaction techniques, and content creation for virtual crime scenes. The study addresses technical challenges related to rendering realistic crime scenes, incorporating interactive elements, and ensuring a seamless integration of the physical and virtual worlds.

The present study introduces a groundbreaking reconstruction approach that amalgamates two disparate techniques for generating 3D meshes of crime scenes. This innovative method leverages the strengths of each individual technique, thereby yielding a final model that exhibits elevated levels of fidelity, whilst concurrently reducing common imperfections such as holes and visual artifacts. One prominent feature of this novel approach is the enhancement in textural quality, which offers a nuanced and reliable representation of the forensic environment under consideration. The synergistic coupling of these two techniques leads to a more robust and enriched 3D model that can better facilitate the investigatory process.The practical implications of this approach are profound. By offering a more comprehensive, accurate, and visually coherent 3D model, the hybrid method significantly contributes to the advancement of current practices in crime scene reconstruction. It enhances the quality and reliability of forensic data, thus providing law enforcement agencies and forensic experts with a more potent tool for investigatory and judicial proceedings.

By developing a practical AR Learning Environment, the research offers a hands-on and immersive training experience for crime scene investigators. It allows trainees to actively engage with virtual crime scenes, practice evidence collection techniques, and improve their investigative skills in a simulated yet realistic environment. The practical contributions of this research highlight the potential for AR to enhance the efficiency, effectiveness, and engagement of crime scene investigation training, ultimately leading to improved real-world investigative outcomes.

6.4 Research Impact

The research presented in this thesis has the potential to make a significant impact on the field of crime scene investigation. Introducing and validating the use of AR technology in training opens new possibilities for improving the skills and performance of investigators in real-world scenarios. The findings of this research have implications for the development of training programs and tools that can enhance the training experience and ultimately contribute to more effective and accurate criminal investigations.

One of the key impacts of this research is its potential to revolutionise the way investigators are prepared for crime scene investigations. Traditional training methods often involve simulated scenarios or classroom-based instruction, which may not fully capture the complexity and dynamics of real crime scenes. By integrating AR technology into the training process, investigators can experience immersive and interactive crime scene simulations that closely resemble real-world situations. This can provide them with valuable hands-on experience and help bridge the gap between theory and practice.

The use of AR technology in training can have several advantages. It allows investigators to visualise and interact with virtual crime scenes, enabling them to practice evidence collection, analysis, and reconstruction in a realistic and controlled environment. This can help them develop and refine their skills, enhance their situational awareness, and improve their decision-making abilities. By incorporating feedback mechanisms and performance assessment tools, AR-based training programs can provide personalised guidance and support to investigators, enabling them to track their progress and identify areas for improvement.

Another potential impact of this research is the advancement of evidence analysis techniques. AR technology can facilitate the visualisation and manipulation of digital evidence overlays, such as bloodstain patterns, trajectory analysis, or bullet trajectories. This can assist investigators in understanding complex spatial relationships, identifying patterns or anomalies, and drawing more accurate conclusions from the evidence. By improving the accuracy and efficiency of evidence analysis, AR technology has the potential to enhance the investigative process and contribute to more reliable and convincing court presentations.

Furthermore, the adoption of AR technology in crime scene investigation can have broader societal implications. Improving the training and skills of investigators can contribute to the overall quality of criminal investigations, potentially leading to more accurate identifications, increased successful prosecutions, and improved public trust in the justice system. The use of innovative technologies like AR can also attract new talent to the field and inspire the next generation of investigators, fostering advancements and innovation in crime scene investigation practices.

6.5 Research Limitations

Despite the promising findings and potential of AR in crime scene investigation training, it is important to recognise the limitations of this research. These limitations highlight areas for further investigation and development to fully realise the benefits of AR technology in the field.

One significant limitation lies in the current state of AR technology itself. While AR has made significant advancements in recent years, it still faces certain technical constraints. For example, the field of view provided by AR devices may be limited, restricting the user's ability to fully immerse themselves in the virtual crime scene environment. Similarly, the processing power of AR devices may pose limitations on the complexity and richness of virtual simulations. These technical constraints need to be addressed and improved upon to ensure a seamless and immersive training experience for investigators.

Another limitation of the research is its focus on a specific AR device, namely the HoloLens. While the HoloLens is a widely recognised and utilised AR device, it is essential to explore the applicability of AR technology across different devices and platforms. Different devices may have varying capabilities, user interfaces, and interaction mechanisms, which could affect the training experience and usability for investigators. Future studies should investigate how AR can be effectively implemented on different devices to ensure broader accessibility and adoption within the crime scene investigation community.

Additionally, the findings of this research are based on a specific set of training scenarios designed to simulate crime scene investigations. While these scenarios provide valuable insights, it is important to acknowledge that they may not capture the full complexity and variations encountered real-world crime scenes. Crime scenes can vary widely in terms of size, location, evidence types, and environmental conditions. Future research should aim to expand the scope of training scenarios to encompass a broader range of crime scene contexts, ensuring that the effectiveness and applicability of AR technology are thoroughly evaluated across different scenarios.

Furthermore, the research may have limitations in terms of the sample size and diversity of participants. The study might have been conducted with a limited number of participants or focused on a specific group of investigators, which could impact the generalisability of the findings. It is crucial to involve a larger and more diverse sample of investigators to ensure the robustness and validity of the research results.

6.6 Future Research

To build upon the findings and advancements made in this research, future studies in the fields of crime scene investigation and AR should explore new avenues and address the identified limitations. These research directions can further enhance the effectiveness and applicability of AR technology in training investigators and improving overall investigative processes.

One important area for future research is the development of more advanced AR applications specifically tailored for crime scene investigation training. This involves refining the user interface and interaction mechanisms to provide a more intuitive and seamless experience for investigators. Improving the visualisation and realism of virtual crime scene elements can enhance the authenticity of training scenarios and better prepare investigators for real-world situations. Additionally, incorporating advanced data analysis techniques, such as pattern recognition and forensic analysis algorithms, into AR applications can provide real-time guidance and feedback to investigators during training, further enhancing their skills and decision-making capabilities.

Another research direction is to conduct comparative studies that evaluate the effectiveness of AR training in comparison to traditional training methods. This can involve comparing the learning outcomes, retention rates, and performance of investigators who undergo AR-based training with those who receive conventional classroom or hands-on training. Such studies can provide valuable insights into the advantages and potential limitations of AR as a training tool, supporting evidence-based decision-making regarding the adoption and integration of AR technology in crime scene investigation training programs.

Furthermore, exploring the integration of AR with other emerging technologies, such as artificial intelligence (AI) and machine learning (ML), holds great promise for future research.

AI and ML algorithms can analyse vast amounts of data and assist investigators in recognising patterns, identifying relevant evidence, and making informed decisions. By integrating AI and ML capabilities into AR training applications, investigators can benefit from intelligent assistance and real-time guidance, enhancing their investigative skills and efficiency.

In addition to technical advancements, future research should also consider the human factors involved in AR-based training. Understanding the cognitive and psychological aspects of using AR in training settings, such as user engagement, motivation, and situational awareness, can help optimise the design and implementation of AR applications for crime scene investigation training.

6.7 Final Thoughts

In conclusion, the research presented in this study showcases the potential of AR technology in crime scene investigation training. By harnessing the capabilities of devices like HoloLens and creating an immersive learning environment, AR has demonstrated its ability to enhance the skills and expertise of crime scene investigators. The theoretical and practical contributions of this research have shed light on the possibilities of utilising AR in forensic investigations, providing valuable insights for the field to build upon.

The findings of this study indicate that AR has the potential to revolutionise the way investigators are prepared for real-world scenarios. The immersive nature of AR training allows investigators to practice at virtual crime scenes, simulating complex and challenging situations they may encounter in their actual work. This technology enables them to analyse evidence, make critical decisions, and gain hands-on experience in a safe and controlled environment.

The implications of this research extend beyond training alone. The adoption of AR in crime scene investigation has the potential to transform the entire investigative process. By enhancing investigators' skills and improving evidence analysis through AR technology, criminal investigations can become more effective and accurate, ultimately leading to better outcomes in terms of identifying perpetrators, solving crimes, and delivering justice.

However, it is important to acknowledge the limitations of the current research. Further development and refinement of AR technology are necessary to overcome technical constraints, such as limited field of view and processing power. Additionally, exploring the applicability of AR across different devices and platforms beyond the HoloLens is crucial for expanding its reach and ensuring wider adoption within the field.

Considering these limitations, future research should continue to explore and innovate in the realm of AR-based crime scene investigation training. The potential for further advancements in user interface design, the incorporation of advanced data analysis techniques, and the integration of AR with other emerging technologies, such as artificial intelligence and machine learning, present exciting avenues for future exploration.

REFERENCES

Appendix: Ethical Approval, Questionnaire and Interviews